TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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MODULARIZATION OF AN EXISTING PRODUCT FAMILY

Master of Science Thesis

Examiner: Professor Tero Juuti
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ABSTRACT

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This Master of Science Thesis was made for Cargotec Oy. Variability of products and the different customer needs have increased the amount of part numbers that have to be maintained. This thesis seeks to find a solution for the problem. The aim of the thesis is to demonstrate how an existing product family can be modularized.

Modularity has been studied a great deal in recent years and a number of different methods have been developed for modularizing product structures. This thesis introduces the Design Structure Matrix, Function Heuristics and Modular Function Deployment methods. The study of these methods, however, indicates that none of these are suitable as such for the modularization of an existing product family. The Brownfield Process is studied in more detail, because it is developed specifically for the modularization of existing product families.

The thesis works as an instruction manual for the case company, in which modularization is explained and the different steps of the Brownfield Process are clarified in detail. The Brownfield Process was applied to the case company's products and a proposal on how the company could modularize their product family was created. In the example case the existing product structures were analyzed and the customer requirements, which cause the need for variation in the products, were studied.

Good results were obtained in the example case, even though the scope of the case was focused on a limited number of crane models and structures. By applying of the process the part numbers could be reduced significantly. Also other benefits for the company could be obtained. During the example case some problems arose, which must be taken into account during a modularization project. The cooperation with the various experts in the company turned out to be very important. The process requires a great deal of information on products, product structures, design principles and customers. The company's marketing, sales and engineering teams have to participate in the process.

It was also noticed, that by modularization alone, long-term benefits cannot be achieved. The company has to make sure, that the manufacturing of the products is made in a way that benefits from modularity. The sales persons have to be trained to sell modular products as well. In order to make sure, that the modular product structure is maintained in the future, the company has to have a certain person or group who owns the modules and interfaces. Their tasks include, for example, ensuring that changes in the products do not violate the modularity.

TIIVISTELMÄ

Pauli Siivonen: Olemassa olevan tuoteperheen modularisointi
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Diplomityö on tehty Cargotec Oy:n Hiab liiketoiminnan tuotekehitysosastolle. Tuotteiden varioituvuus ja erilaiset asiakastarpeet ovat kasvattaneet ylläpidettävien nimikkeiden määrää huomattavasti. Tähän ongelmaan pyritään löytämään ratkaisu. Työn tarkoituksena on osoittaa, kuinka jo olemassa oleva tuoteperhe voidaan modularisoida.

Modulaarisuutta on tutkittu viime vuosina hyvin paljon, ja useita eri menetelmiä on kehitetty modulaaristen tuoterakenteiden suunnitteluun. Diplomityössä tutustaan Design Structure Matrix, Function Structure Heuristics sekä Modular Function Deployment menetelmiin, joilla voidaan suunnitella modulaarisia tuoterakenteita. Tutkimus kuitenkin osoittaa, että mikään näistä menetelmistä ei sovellu sellaisenaan jo olemassa olevan tuoteperheen modularisointiin. Työssä tutkitaan syvällisemmin Brownfield prosessia, joka on kehitetty erityisesti olemassa olevien tuoteperheiden modularisointiin.

Työ toimii kohdeyritykselle ohjekirjana, jossa selvitetään mitä modulaarisuus tarkoittaa ja käydään Brownfield prosessin eri vaiheet yksityiskohtaisesti läpi. Brownfield prosessia sovellettiin käytännössä yrityksen tuotteisiin ja näin luotiin ehdotelma siitä, kuinka yritys voisi modularisoida tuoteperhettään. Esimerkkitapauksessa analysoitiin olemassa olevia tuoterakenteita ja tutkittiin asiakastarpeita, jotka edellyttävät variaatiota tuotteissa.

Esimerkkitapauksesta saatiin hyviä tuloksia, vaikka kohdealue olikin rajattu koskemaan vain tiettyjä nosturimalleja ja -rakenteita. Soveltamalla prosessia nimikkeiden määrää saatiin vähennettyä huomattavasti. Myös muita hyötyjä yritykselle pystyttiin havaitsemaan. Esimerkkitapauksen aikana ilmeni myös ongelmia, joita tulee huomioida modulaarisuusprojektin aikana. Yhteistyö yrityksen eri asiantuntijoiden kanssa osoittautui hyvin tärkeäksi. Prosessin läpivienti edellyttää hyvin paljon tietoja tuotteista, tuoterakenteista, suunnitteluperiaatteista ja asiakkaista. Prosessiin tulee siis osallistua yrityksen markkinointi-, myynti- ja suunnittelutiimit.

Esille nousi myös se, että pelkällä moduloinnilla ei voida saavuttaa pitkäaikaisia hyötyjä. Yrityksen tulee panostaa myös siihen, että tuotteiden valmistuksessa on huomioitu modulaariset tuoterakenteet ja että myyntihenkilöstö on koulutettu myymään modulaarisia tuotteita. Jotta modulaarinen tuoterakenne säilyy myös jatkossa, yrityksessä tulee olla tietty henkilö tai ryhmä, jotka hallinnoivat moduuleita ja rajapintoja. Heidän tehtävänä on muun muassa varmistaa, että muutokset tuotteissa eivät riko tuotteen modulaarisuutta.

PREFACE

This Master of Science Thesis was made for Hiab, which is part of Cargotec Oy. Before starting this thesis I have worked one summer as a trainee in the same R&D department, so the products and tools used in the department were familiar to me. However working on this thesis brought me a deeper knowledge of the products and modularization methods.

I would like to thank my examiner Professor Tero Juuti for helping me to come up with an interesting subject and for providing feedback on my work. I would also like to thank my supervisors Ismo Inkinen and Toni Kymäläinen. Your support, advices and opinions have been very important for me and this thesis. I have also been grateful for the support of the whole forestry cranes department.

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Raisio, 14.8.2015

Pauli Siivonen

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

BfP	Brownfield Process
BOM	Bill of material
CAD	Computer-aided design
CSL	Company Strategic Landscape
DfV	Design for Variety
DfX	Design for X
DPM	Design property matrix
DSM	Design Structure Matrix
EN	European Standard
K-Matrix	Configuration matrix
kg	Kilogram
kNm	Kilonewton meter
m	Meter
MFD	Modular Function Deployment
MIM	Module indicator matrix
PFMP	Product Family Master Plan
PMM	Product management map
PSBP	Product Structuring Blue Print
QFD	Quality function deployment
R&D	Research and development
V-Matrix	Compatibility matrix
VoX	Voice of X

1. INTRODUCTION

First the case company is introduced. Then aims of the thesis and the framework are described. Also the benefits for the company and their customers are explained.

1.1 Company profile

Cargotec Oy is a Finnish company that manufactures cargo-handling machinery. Cargotec operates in more than 100 countries and it has three business areas MacGregor, Kalmar and Hiab. MacGregor provides products and services for handling marine cargo and offshore loads. Kalmar offers cargo handling solutions and services to ports, terminals, distribution centers and for industrial applications. The case company, Hiab, manufactures products for load handling on on-road transports. Cargotec's sales in 2014 totalled 3.4 billion Euros and they employed approximately 11,000 people. Hiab's share of the sales was 840 million Euros and they employed at the end of 2014 2,571 peoples in 31 countries. (Cargotec, 2015)

The product range of Hiab includes HIAB loader cranes, JONSERED loader, recycling and forestry cranes, LOGLIFT forestry cranes, MOFFETT truck mounted forklifts and MULTILIFT demountables as well as DEL, WALTCO and ZEPRO tail lifts. Hiab's customers range from large companies to small enterprises and their fields of businesses include transportation companies, municipalities and governments, fleet operators, single truck owners, rental companies and truck manufacturers. (Hiab, 2015)

1.2 Objectives and framework of the thesis

Modularization has been studied a lot in the past years and especially in the automotive industry modularity has been used to create an advantage over competitors. Volkswagen is known for using modularity in their product development (Raynal, 2013) and now Toyota is doing the same (Teknavi, 2015). According to Teknavi by using modularity Toyota can build their new production lines for half the price in comparison to 2008. A new factory can be built 40% cheaper and the savings in production are 20% because it is simpler and more flexible. With figures like that it is clear why companies invest in modularity and that is also the reason for this thesis. This thesis will give the reader an understanding of the basics of modularity and it will introduce the reader to different modularity methods.

There are a lot of different approaches to develop a modular product or product family as will be explained in Chapter 3. This thesis will provide a proposal on how to define a modular product family using the so-called Brownfield Process. It will describe the different steps of the Brownfield Process and give an example on how to use the process.

Due to the limited resources and time for this thesis, only an example case of a modular product development by using the Brownfield Process is given. A whole product family could not be modularized within the given timeframe. The example case is described in more detail in Chapter 5.

This thesis will provide answers to the following questions:

- What is modularity?
- What is the Brownfield Process?
- How to apply the Brownfield Process?
- How does the case company benefit from the Brownfield Process?

The object of this thesis is to introduce the case company to modularity and the Brownfield Process. This thesis aims to provide the company the required information to fulfill a modular product development process for their existing product family by using the Brownfield Process.

1.3 Benefits of the thesis

1.3.1 Company benefits

By successfully fulfilling a modularization project, different benefits for the company can be achieved. These benefits are discussed in Chapter 3.2. The desired benefits of this thesis for the company are clear guiding principles for the designers on how to use the Brownfield Process to re-design their existing product family to a more modular one. The aims of the modularization process for the case company are to reduce the part numbers, which has a direct impact on cost savings in development, production, storage and logistics. Additional targets are material cost reduction, lead-time reduction and minimization of so-called b-orders. B-orders are delivery-specific orders which are made to fulfill specific customer requirements.

1.3.2 Customer benefits

Also the customer benefits from a modular product family. With reduced material costs and cost savings in development, production, storage and logistics the company is able to provide the products at a more competitive price. In addition the sales-delivery process will be shorter and the customer will be able to receive the product faster. Moreover, the time at the repair shop will be shorter, because the faulty module can be exchanged to a new one and the customer can continue working while the repair facility examines the faulty module to find the problem. Upgrading the product will also be easier because of standardized modules and interfaces. So if a customer needs new features to his product, he could simply order a module including these features.

2. INTRODUCTION TO FORESTRY CRANES

This chapter describes a forestry crane and the general application areas. Also the main parts, terms and definitions related to forestry cranes are explained.

2.1 Definition of a forestry crane

According to loader crane standard (EN 12999, 2011) loader cranes are described as a “powered crane comprising a column, which slews about a base, and a boom system which is attached on to the top of the column, usually fitted on a commercial vehicle (including trailer) with a significant residual load carrying capability, and being designed for loading and unloading the vehicle as well as for other duties as specified by the manufacturer in the operator's manual”. The standard also describes timber handling cranes, also known as forestry cranes, to be loader cranes specifically designed, manufactured and equipped with grapplers for loading/unloading of unprepared timber such as tree trunks.

A forestry crane consists of a base, column and hydraulically moved booms. Some models are fitted with a telescopic boom system that can be extended. The main parts of a forestry crane are shown in Figure 2.1 and they are named according to EN 12999:2011.

1. Base
2. Column
3. First boom
4. Second boom
5. Boom extension
6. Stabilizer leg
7. First boom cylinder
8. Second boom cylinder
9. Slewing mechanism
10. Extension cylinder
11. Stabilizer extension cylinder
12. Stabilizer cylinder
13. Control valve
14. Stabilizer valve
15. Hanger
16. Rotator
17. Grappler
18. Grappler cylinder
19. High pressure filter

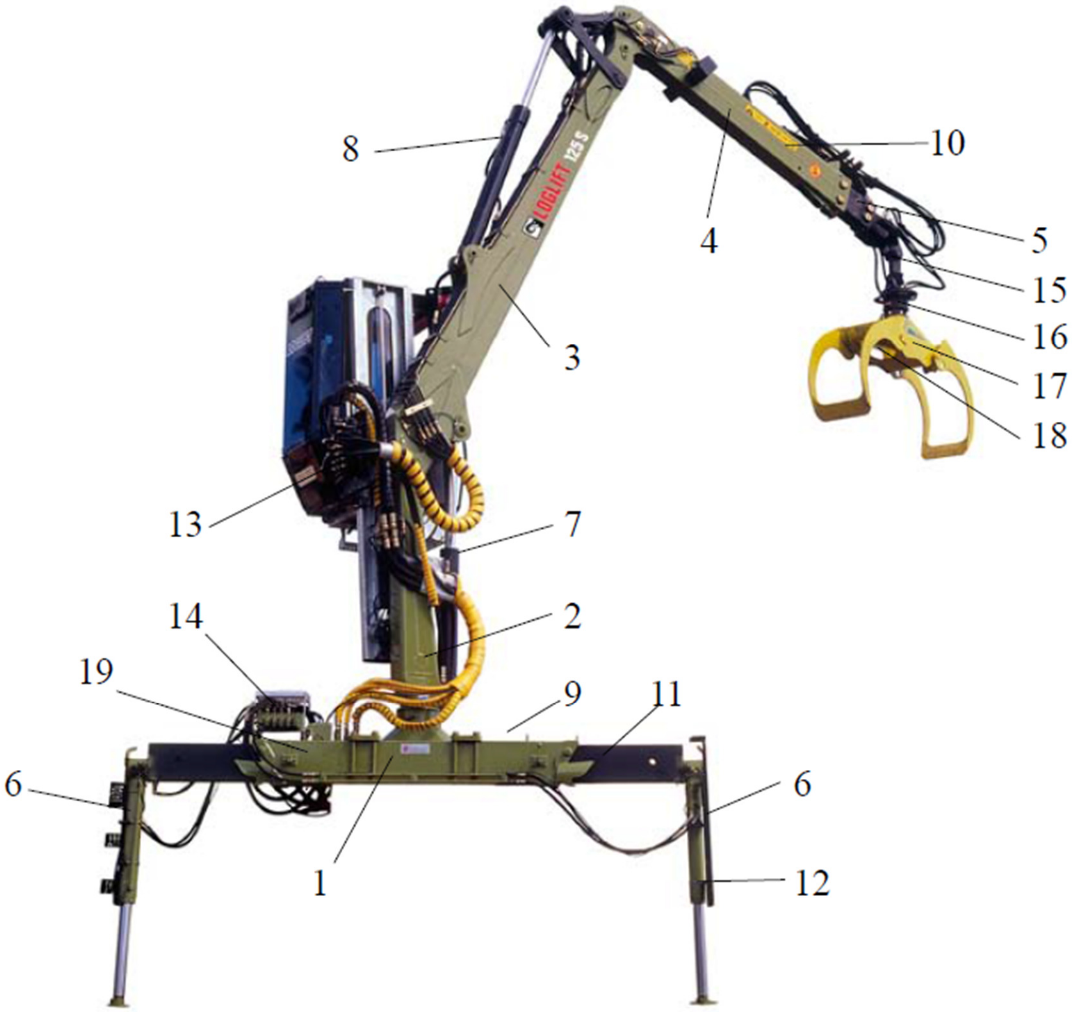

Figure 2.1. Main parts of a forestry crane (Hiab, 2015).

2.2 General applications

Smaller forestry cranes are used to handle cut-to-length timber, whereas larger ones are used for loading full-length stems. For example, Hiab's LOGLIFT cut-to-length forestry cranes range from a lifting capacity of 2000 kg to 4000 kg and cranes designed to load full-length timber from 4000 kg to more than 8000 kg. There are also available foldable, so called Z-models, that can be used to lift cut-to-length and full-length timber. Rated capacity, i.e. lifting capacity and outreach are the main terms to describe the performance of a crane. Figure 2.2 – Figure 2.5 show different types of forestry cranes. The rated capacity as well as outreach is given in the caption.

Figure 2.2. LOGLIFT 108S cut-to-length crane with a lifting capacity of up to 3400 kg (109 kNm) and outreach of up to 10.1 m (Hiab, 2015).

Figure 2.3. LOGLIFT 115Z foldable cut-to-length crane with a lifting capacity of up to 3270 kg (110 kNm) and outreach of up to 9.25m (Hiab, 2015).

Figure 2.4. LOGLIFT 251S tree-length crane with a lifting capacity of up to 5800 kg (235 kNm) and outreach of up to 8.9m (Hiab, 2015).

Figure 2.5. LOGLIFT 265Z foldable tree-length crane with a lifting capacity of up to 6640 kg (225 kNm) and outreach of up to 9.46m (Hiab, 2015).

2.3 Terms and definitions

The following terms and definitions describe the structure and use of forestry cranes. The terms and definitions listed below are collected from EN 12999:2011 and Hiab internal sources.

Base is the housing incorporating anchoring points and bearing for the slewing column.

Boom is the structural member in the boom system of the loader crane.

Boom extension is the part of the boom which can be extended or retracted to vary its length.

Boom system consists of booms, boom extension and cylinders.

Column is the structural member which supports the boom system.

Dead load is the force due to masses of fixed and movable crane parts which act permanently on the structure while the crane is being used.

Gross lifting moment is the moment produced by the lifting cylinder with maximum working pressure when the boom is in the most optimal position to the lifting cylinder. It is a derived value and it doesn't take into account frictional loss.

Gross slewing moment is the slewing moment produced by the slewing system with maximum working pressure. It is a derived value and it doesn't take into account frictional loss.

High seat is the control station connected to the column. It is consequently rotating with the crane. Some crane models have a cabin instead.

Load chart is a chart that shows the rated capacity load for all boom configurations.

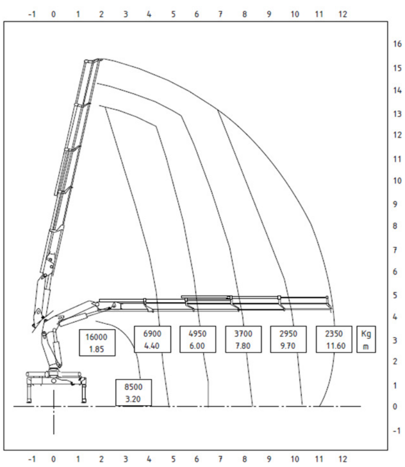

Figure 2.6. Example of a load chart (EN 12999, 2011).

Load plate is a plate that shows the rated load capacity at various load attachment positions along a horizontal line.

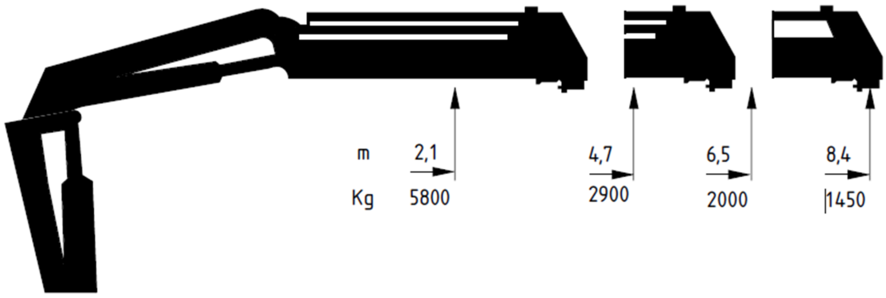

Figure 2.7. Example of a load plate (EN 12999, 2011).

Maximum working load stands for the maximum load that may be lifted.

Maximum working pressure stands for the maximum pressure in pump circuit or individual working functions.

Net lifting moment is the rated capacity multiplied by outreach.

Net slewing moment is the actual slewing moment measured from the crane.

Outreach is the horizontal distance between the axis of rotation of the column and point of load attachment.

Rated capacity is the load that the crane is designed to lift for a given operating condition.

Slewing refers to the rotational movement of the column and boom system about the axis of the column.

Slewing angle refers to the angle that the crane can rotate around the columns axis.

Stabilizer provides aid to the supporting structure connected to the base of the crane or to the vehicle to provide stability.

Stabilizer extension is the part of the stabilizer capable of extending the stabilizer leg laterally from the transport position to the operating position.

Stabilizer leg is the part of a stabilizer which is in contact with the ground to provide the required stability.

Total lifting moment is the sum of net lifting moment and the moment produced by dead loads.

3. MODULAR PRODUCT DEVELOPMENT

In this chapter modularity is explained. Also an insight on main types of modularity is given and different modularization methods are introduced.

3.1 Modularity and Standardization

To sell products, companies should consider and listen to the different needs of the customers. Because of these needs, companies have to manage a greater variety of products. The competition is also growing fast, which forces companies to develop more efficient business strategies to decrease costs, increase quality and reduce response time. Modularization has helped companies to face these challenges by bringing the advantages of standardization and rationalization with customization and flexibility. (Miller & Elgård, 1998)

Standardization means that several components from a system are replaced with a single component which can perform the same functions. Component standardization can be within a product in which case a number of unique components in a product are replaced by a common component. Component standardization among products means that some unique components in different products are replaced by a common component. In component standardization among product generations common components are used in different products. (Perera, et al., 1999) Standardization enables modularization (Pakkanen, 2013).

Modularity has been researched a lot during the last years and researchers have different opinions on how to define modularity. The main idea, however, is to create different product variants using pre-designed modules with well-defined interfaces. (Miller & Elgård, 1998) (Okudan Kremer & Gupta, 2012)

A standardized interchangeable unit is defined as a module. With the use of modules the system can be manufactured without the need of order-specific customization. (Sarinko, 1999) A module has only loose connections to the other components and modules of the system so that the different modules can be developed separately.

A modular system consists of modules that can be replaced. Timo Lehtonen describes in his doctoral thesis "*Designing Modular Product Architecture in the New Product Development*" that five types of interchangeability within a system exist (Lehtonen, 2007). These five types of modularity were originally introduced by William Abernathy and

James Utterback in their book "*Pattern of Industrial Automation*" published in 1978. The types are as follows (Sarinko, 1999):

1. Component-sharing modularity: the same module can be used in different base systems. Module can be used in different product family.
2. Component-swapping modularity: two or more modules can be swapped to the same base system and they form different product variants of the same product family.
3. Cut-to-fit modularity: the parametrical values of a module can be determined case by case.
4. Bus modularity: different modules can be placed in different positions to the base system.
5. Sectional modularity: through standardized interfaces a group of modules can be combined in any order.

The types of modularity are shown in the figure below.

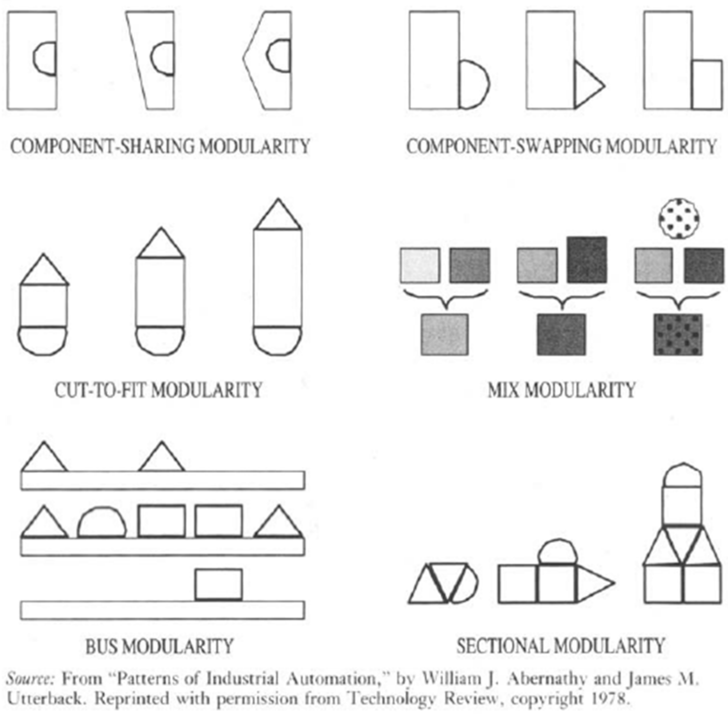

Figure 3.1. Types of modularity (Lehtonen, 2007).

Figure 3.1 also includes mix modularity. In mix modularity the modular system consists of mixable ingredients, but Lehtonen dismissed it as a form of modularity, as it is impossible or impractical to define the solution level for ingredients in a non-fixed space (Lehtonen, 2007).

3.2 Benefits of modularization

A modular product or product family brings many advantages to a company. By designing modular products, the designer can use same modules in different products and so have a large variety of products with less different components. If a company already has a modular product, it is easier and faster to design a new product since they already have designed modules with well defined interfaces that can be used. This can lead to, for example, more efficient use of research and development (R&D) and shorter time to market. By using existing and well-tried modules in new products the R&D department needs less time to design the main features of the product and they can focus on the new features that will make them stand out from the competition.

Lehtonen et al. performed a modularization process for a company and described their methods and results in their article “A Brownfield process for developing of product families”. They achieved the following benefits for the company (Lehtonen, et al., 2011):

- Comprehensive analysis of customer needs and above all directing them to the products in a controlled way.
- Managing variety without losing control of the whole concept.
- Utilizing the commonality of the product family.
- Expediting the material management in production.
- Enabling variation during the production.
- Expediting the order-delivery process.
- Scaling of the scheme throughout the whole product concept, not just in a single product.
- Simplifying of the product range and elimination of unnecessary combinations.

Hansen & Sun (2010) performed a study that incorporated 40 industrial modularization cases. They studied the expected and realized benefits in the cases. Their empirical observations are the following:

- Product modularity reduces costs in the product life cycle due to the possibilities of economy of scale in production.
- Product modularity reduces delivery time due to the possibilities of postponement in supply chain.
- Product modularity enhances speed in the product development process due to the possibilities for distribution of activities.
- Product modularity enhances speed in the product development process due to well-known structures in the product development project management.
- Product modularity enhances speed in the introduction of new product variants due to the reuse of components and structures.

- Product modularity enhances the variety due to the flexibility in configuration of the final product.
- Product modularity enhances organizational flexibility due to the ease in communication of the product structure.
- Product modularity enhances organizational learning due to the inherent structure for accumulation of knowledge.

3.3 Overview of modularization methods

There have been developed a number of different modularization methods. Typically each method aims to optimize certain criterions with different input values. According to Jose and Tollenaere (2005) the methods can be divided into the following categories: clustering methods, graph and matrix partitioning methods, mathematical programming methods, artificial intelligence and genetic algorithms and other heuristics. Some well-known methods are Design Structure Matrix (DSM), Function Structure Heuristic method and Modular Function Deployment (MFD). (Eiden, 2013) (Borjesson, 2010) (Hölttä-Otto, 2005) These methods are introduced in the following sections.

In academic publications in which modularization are discussed, the detailed design activities for developing of a successful modular product are seldom explained. The knowledge related to the design and management of modular products is often considered as a core competence in each company and therefore it is not revealed to the competitors on a larger scale. Thus there are some challenges in validating the modularization methods because all the details are not published. However several modularization publications include method-like guiding principles. (Pakkanen, 2015)

3.3.1 Design Structure Matrix

DSM is a good example of a clustering method. First the product is divided into smaller parts. The components or functions are placed on the row and column headers of a matrix. The interactions of the components or functions are identified by mapping them against each other and then they are marked with coupling coefficients (-2, -1, 0, 1 or 2) in the matrix. The coupling coefficients depend on the strength of the relation and whether the relation is beneficial or undesired. With the use of a clustering algorithm the components or functions are reordered and can be grouped so that the interactions within clusters are maximized and between the clusters minimized. These groups form the possible modules of the product. (Okudan Kremer & Gupta, 2012) (Hölttä & Salonen, 2003) Figure 3.2 shows an example of an unclustered DSM matrix and Figure 3.3 shows the DSM matrix after the use of a clustering algorithm.

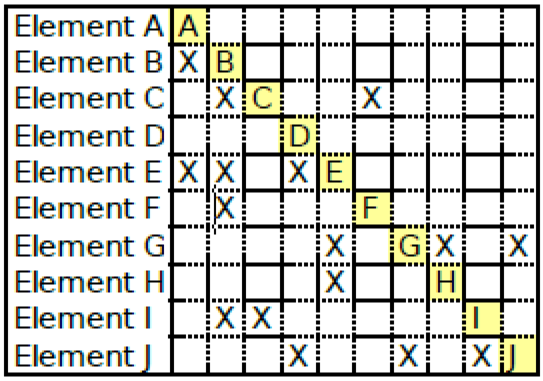

Figure 3.2. Example of an unclustered DSM matrix. (Eiden, 2013)

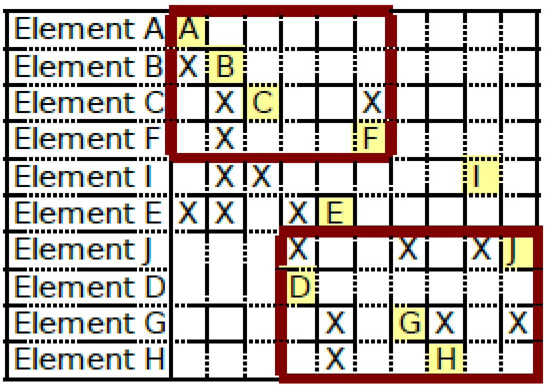

Figure 3.3. The DSM matrix after applying clustering. (Eiden, 2013)

3.3.2 Function Structure Heuristic

Stone et al. (2000) defines module heuristics as "a method of examination in which the designer uses a set of steps, empirical in nature, yet proven scientifically valid, to identify modules in a design problem". Function structure heuristic method does not define exact steps on how to design the product from beginning to end. It consists of two phases, the functional modeling phase and the product architecture phase. In the first phase customer requirements are gathered and a functional model is created. In the second phase module candidates are identified by applying the heuristics approach and then the modular concepts are generated. The functional model should include all input and output flows in the system. These flows represent the energy, material and signals that move through the product. (Eiden, 2013) By observing these flows Stone et al. formulated three heuristics to identify modules based on the three possibilities that a flow can experience (Stone, et al., 2000):

1. Dominant flow: a flow may pass through a product unchanged.
2. Branching flow: a flow may branch, forming independent function chains.
3. Conversion-transmission flow: a flow may be converted to another type.

In the heuristic approach the product is observed from the perspective of these flows and the modules are formed based on the flow characteristics (Eiden, 2013). An example of a functional model that is used to identify modules by the use of flow branching heuristics is given in Figure 3.4.

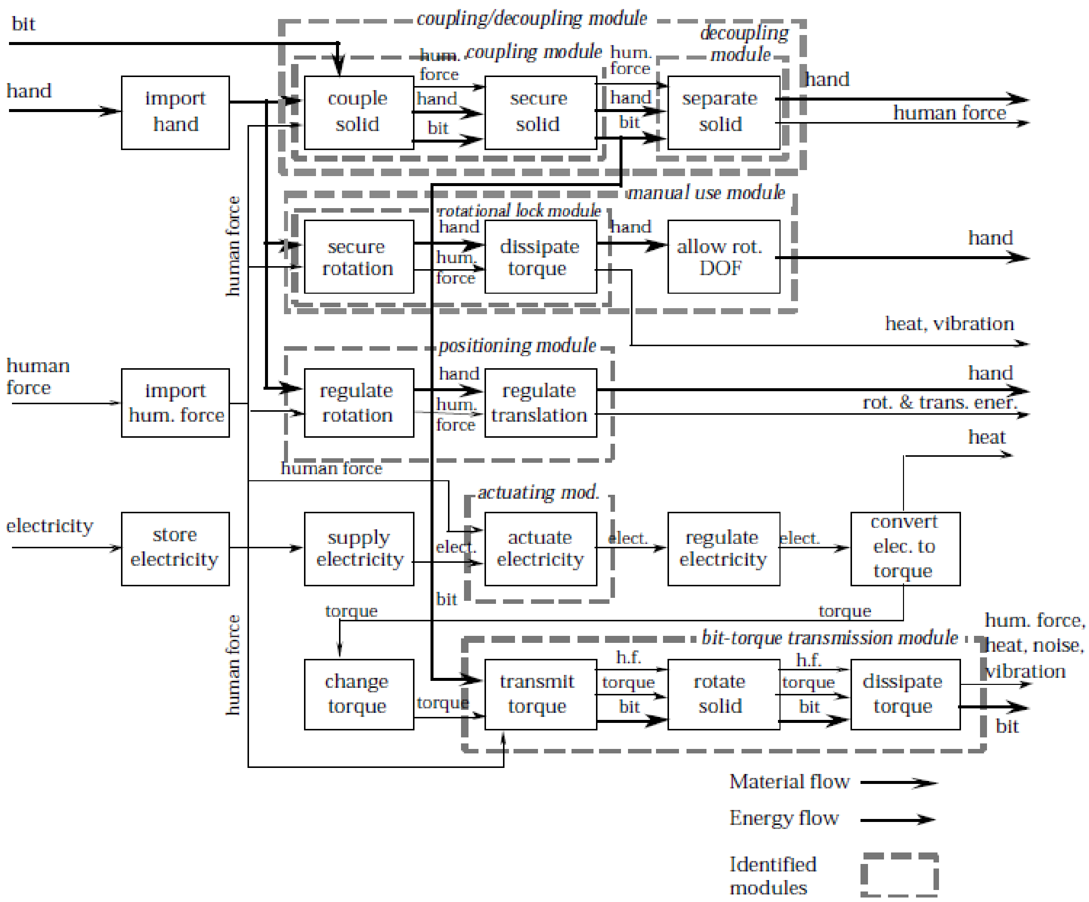

Figure 3.4. Functional model of a power screwdriver. (Stone, 1997)

3.3.3 Modular Function Deployment

MFD focuses on the strategic business objectives and it is more customer oriented. Product data and information is gathered together into a collection of matrices known as the product management map (PMM). An example of a PMM is given in Figure 3.5.

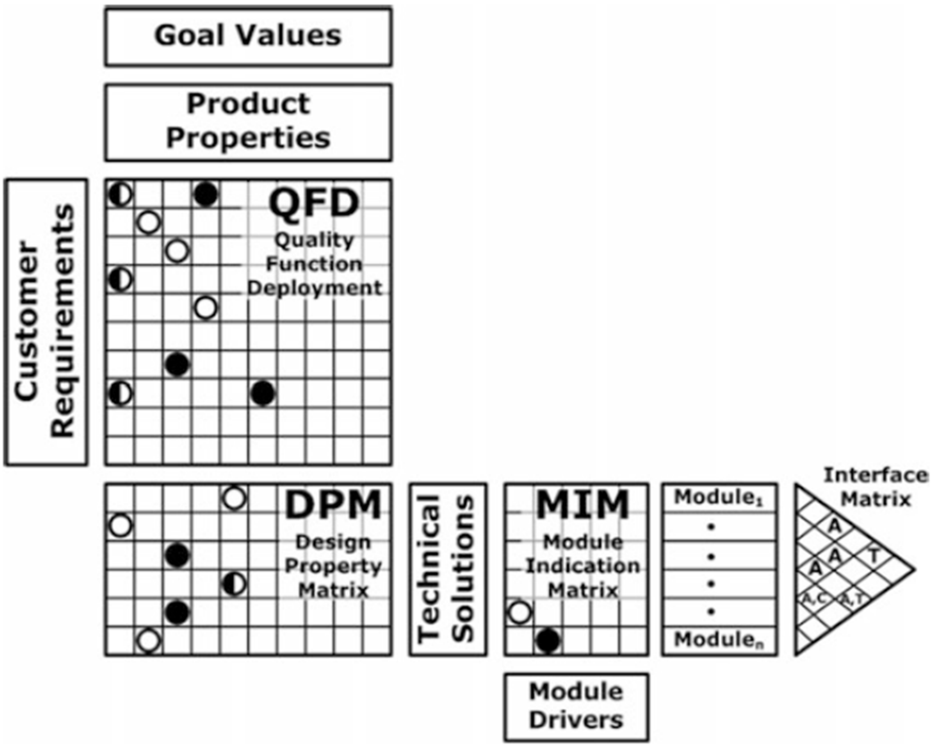

Figure 3.5. Product management map (PMM) (Simpson, et al., 2013).

Erixon (1996) describes that there are five steps in MFD. These steps are:

1. Clarify product specifications.
2. Analyze functions and select technical solutions.
3. Identify possible modules.
4. Evaluate concepts.
5. Improve each module.

Chapter 4 written by M. Lange and A. Imsdahl of (Simpson, et al., 2013) describes these steps as followed. For the first step a quality function deployment (QFD) matrix is used to clarify customer requirements by mapping them against product properties as shown in Figure 3.5. In the second step the technical solutions are defined and decided. The design property matrix (DPM) shows these decisions by demonstrating the relationship between product properties and technical solutions. In step three module drivers are used to indicate the strategic reason a module should be created. According to Erixon (1996) module drivers are a number of different criteria behind modularization along the entire product life cycle. Module drivers can be grouped into “Voices of X” (VoX) groups depending on whom the specific driver affects. Lange and Imsdahl (Simpson, et al., 2013) list 12 module drivers and group them as shown in Figure 3.6.

- Voice of Customer
    - Different Specification
    - Styling
- Voice of Engineering
    - Carry Over
    - Technology Evolution
    - Planned Design Change
- Voice of Manufacturing
    - Common Unit
    - Process and/or Organization
- Voice of Quality
    - Separate Testability
- Voice of Supply Chain
    - Supplier Availability
- Voice of After Market
    - Service and Maintenance
    - Upgrading
    - Recycling

Figure 3.6. List of module drivers.

The different "Voice of X" groups represent a group of experts and these groups form together the core team of the MFD project. In the module indication matrix (MIM) the module drivers are mapped against the technical solutions. In step four module concepts are evaluated by considering how, with the help of standardized interfaces, the modules will be put together. It is important to evaluate the interfaces carefully, because standardized interfaces allow the product to be modular and flexible. In MFD seven types of interfaces are defined: attachment, transfer, spatial, command and control, field, environmental and user. In the last step each module concept is improved with "Design for X" (DfX) approaches. For example Design for Manufacturing or Design for Assembly depending on why the company chose to use MFD. (Simpson, et al., 2013) (Erixon, 1996)

3.3.4 Summary of the methods

It is difficult to choose which method is the most suitable in a specific case. All three methods introduced in this chapter have their own strengths and weaknesses. According to studies from Hölttä-Otto et al. (Hölttä & Salonen, 2003) (Hölttä-Otto, 2005) "the function structure heuristic method, the DSM and the MFD, given identical inputs, produce different results”. This is because of the different viewpoints and application areas of the methods. The functionality and the interface simplicity are the main objects of the function structure heuristic method. The DSM considers only the simplicity of the interfaces, but it can also consider other company issues if other strategic matrices are used as well. The main focuses of MFD are the various strategic issues and so the decisions about the functions and interfaces of the product are left to the designer. (Hölttä & Salonen, 2003) (Hölttä-Otto, 2005)

Daniilidis et al. (2011) introduced a classification framework for modularization methods. In that framework different methodologies to achieve modularity are classified according to parameters that describe the application area and the capabilities of an approach. An example of a classification framework is shown in Figure 3.7.

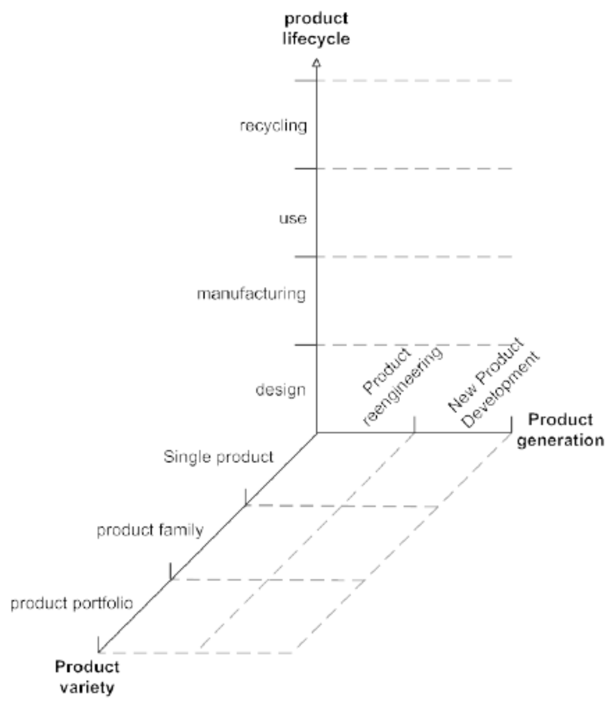

Figure 3.7. Classification framework for modularization methods (Daniilidis, et al., 2011).

The classification framework consists of three dimensions which are product lifecycle, product generation and product variety. The product lifecycle dimension considers the design, manufacturing, use and recycling of the product. The product generation dimension includes the aspects of new product development or product re-engineering. The methods suitability for developing of single products, product families or product portfolios is considered in the product variety dimension. Figure 3.8 shows the classification frameworks for Function Heuristics, DSM and MFD. It also shows the framework for Design for Variety (DfV) which is not considered in this comparison.

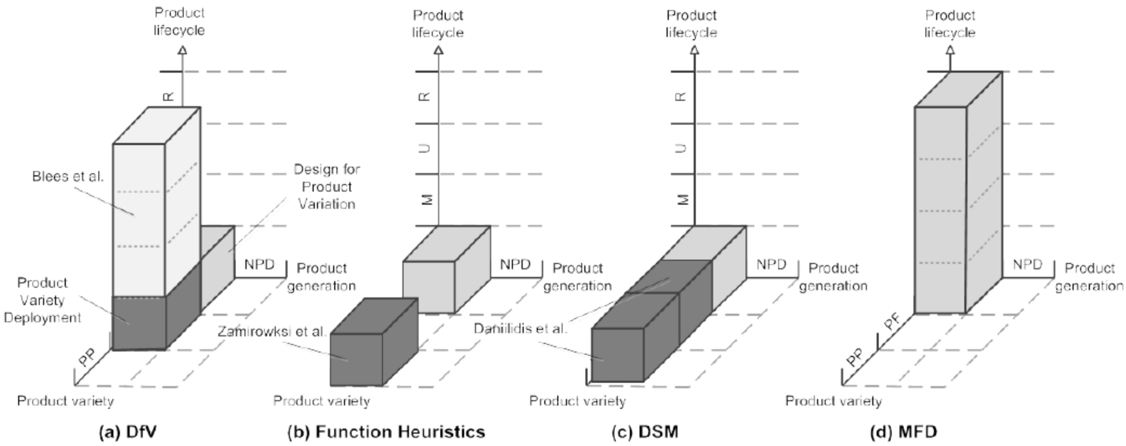

Figure 3.8. Classification framework for DfV, Function Heuristics, DSM and MFD. (Daniilidis, et al., 2011)

The function structure heuristic method is the most suitable choice to define exact module boundaries, in other words, to minimize the interactions at each boundary. With the use of heuristic method, the modules are designed in a way that they will not affect the rest of the product, so that each module is interchangeable. For modularizing a more complex system with too many interactions for a person to handle, the most appropriate choice is the DSM. It can also be used to simplify module boundary interactions. With the help of computerized algorithms it can handle complex problems quickly, but the user has to be critical about the solutions, because it can suggest some irrational modules. For strategy based modularization the MFD is the most suitable choice. However for MFD the customer requirements and the opinions of the different stakeholders such as engineers, manufacturers and after sales, have to be clear. (Hölttä & Salonen, 2003)

These methods do not provide a good basis for modularization of an existing product family. The focus is on single products or on new concepts rather than existing product families. For this reason the so-called Brownfield Process was chosen for this thesis. The Brownfield Process is discussed in detail in Chapter 4. (Hölttä & Salonen, 2003) (Pakkanen, 2015)

4. BROWNFIELD PROCESS

In this chapter the Brownfield Process is introduced and the different steps of the process are described in detail.

4.1 Overview of the process

Developing a new product has higher risks than upgrading current products. There is a risk that a new product will not match the customers' needs and markets have usually dominant designs, which affect the customers' choices. New products have in addition usually an influence on manufacturing, maintenance and sales. However, there are many product development processes that focus on new products and just a few that are used to redesign old products. A Brownfield Process (BfP) describes a development process in a case where the existing market and product family is used. Because of the existing structures there are limitations in design and solutions. The old products and solutions may contain "waste" that has to be cleaned away before the rest of them are useful. This means, for example, that the quantity of parts used in a product family might be unnecessarily high or that some product solutions and variants are not matching any customer requirements, hence making them useless. (Lehtonen, et al., 2011)

The BfP is an incremental development process and the first version was presented in Lehtonen et al. (2011). The process was divided into five steps: defining business targets, drafting the proposed module architecture, analyzing the customer requirements, analyzing the minimum amount of variation and describing the improved product structure. Pakkanen updated this process in his doctoral thesis (2015) and introduced a new ten step BfP. The updated BfP is divided into more manageable sections and the content of the process is defined in more detail. Moreover, it includes new steps that have not been discussed in earlier publications. The updated BfP is presented in Figure 4.1. In order to provide competitiveness and profitability, the results of the design have to fit the business environment of the company and therefore the process starts and ends by considering the business issues. (Pakkanen, 2015)

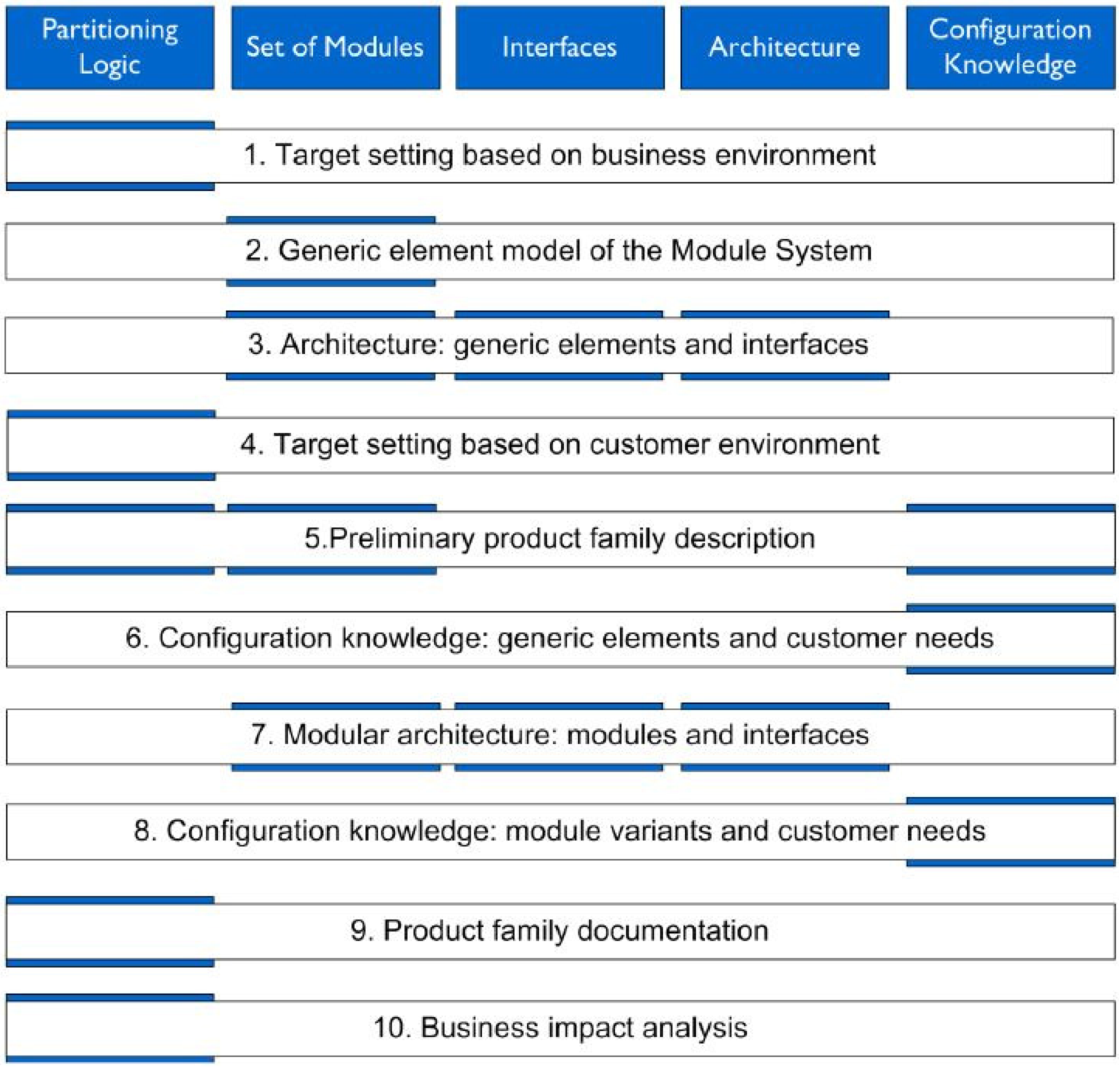

Figure 4.1. The ten steps of the Brownfield Process (Pakkanen, 2015).

The top row of Figure 4.1 shows the main elements of the Module System presented in Pakkanen et al. (2013). It also shows which element of the Module System is considered in the different steps of the BfP by using blue rectangles behind the step's name bar. The Module System consists of the following elements (Pakkanen, et al., 2013):

- **Partitioning logic** describes reasoning leading to a certain module division.
- **Modules** are building blocks of the Module System.
- **Interfaces** enable interdependence and interchangeability of the modules.
- **Architecture** defines the layout structure of the Module System and how modules and their interfaces are located in the product.
- **Configuration knowledge** describes compatibility and constrains of the modules and customer needs.

This kind of divisioning into five elements helps understanding what kind of information is needed in the development of a modular product family. The different steps of the BfP seek to define the content of these five elements. Each step aims at contributing to one or more elements of the Module System. (Pakkanen, 2015)

Some benefits of the BfP are listed in chapter 3.2. The main reason to use the BfP is a situation where the product range, including parts and assemblies, has increased over time. This could lead to a situation where existing products do not necessarily fit business and customer requirements anymore in an optimum way and the wide variety of products could also lead to confusions in the sales-delivery process. By using the BfP the base idea is that the products have design potential from the viewpoint of increasing commonality with possibilities to satisfy variability needs. This would increase the possibilities of design re-use. One reason to use the BfP is also to get out of the situation where companies design solutions fit all the customer needs without thinking about re-usability. The reason for this might be a strict delivery schedule that caused low possibilities for the designing of re-usable assets. By using the BfP, the situation is intended to develop in the direction in which, with smaller sets of solutions and their parts, the same customer needs could be fulfilled. One goal of the BfP is to increase the use of re-usable parts in the sales-delivery process. The aim of the BfP is not to create innovative new solutions but to concentrate on rationalization of an existing product assortment. (Pakkanen, 2015)

4.2 Step 1: Target setting based on business environment

The first step for the Brownfield process is to define the business targets of the company and the reasons on why the company needs a modular product family. Some business targets for companies could be for example *improved R&D efficiency*, *faster Time To Market* or *reduction in component quality issues*. Companies could have outdated or lacking knowledge about the business objectives related to the designing of a modular product family. The business objectives are important for the whole design process and that is why this step is vital. The group that does the actual development work needs the results of this step the most, because the business objectives have an influence on the chosen designing approach. (Pakkanen, 2015)

Pakkanen (2015) recommends that this step should be done in a workshop-type environment in which people from the different departments of the company participate. Participants should provide input by naming their critical viewpoints and estimations of the requirements and possible benefits or disadvantages of modular products.

In this step the scope of the BfP is also decided. Because the BfP focuses on modularization of existing products the scope should be determined by observing the existing product assortment. If the company has a wide range of product families and product variants it could be wise to narrow the focus of the modularization process to some specific products. If the product assortment can be narrowed down for the modularization process, the complexity of the product development activities can be reduced and this makes the development of standardized or configurable interfaces and product elements easier. But if the focus is only on specific products it is only possible to gain good results in that specific area. This first step contributes to the partitioning logic of the Module System, because the reasons for partitioning of the product assortment are analyzed from a business environment perspective. (Pakkanen, 2015)

For defining the business objectives two different methods can be used. The first method was introduced by Juuti (2008) and it is a cause-effect chain of the benefits using commonality and variability. The second method is the Company Strategic Landscape (CSL) which is discussed for example by Lehtonen (2007). The methods are presented in the following chapters.

4.2.1 Cause-effect chain

Juuti created a cause-effect chain that answered the question “Why to design variety with commonality to Technical System?” and included it in his doctoral thesis (2008). Pakkanen (2015) suggests using the cause-effect chain in situations in which the company has a common understanding about the benefits of the modularization process. Because the cause-effect chain shows benefits from different viewpoints, it can be used to confirm presumptions about the objectives and benefits. It also shows how the different issues and benefits are connected. It can also be used to define the areas where the greatest benefits could be achieved. (Pakkanen, 2015) Figure 4.2 shows the cause-effect chain.

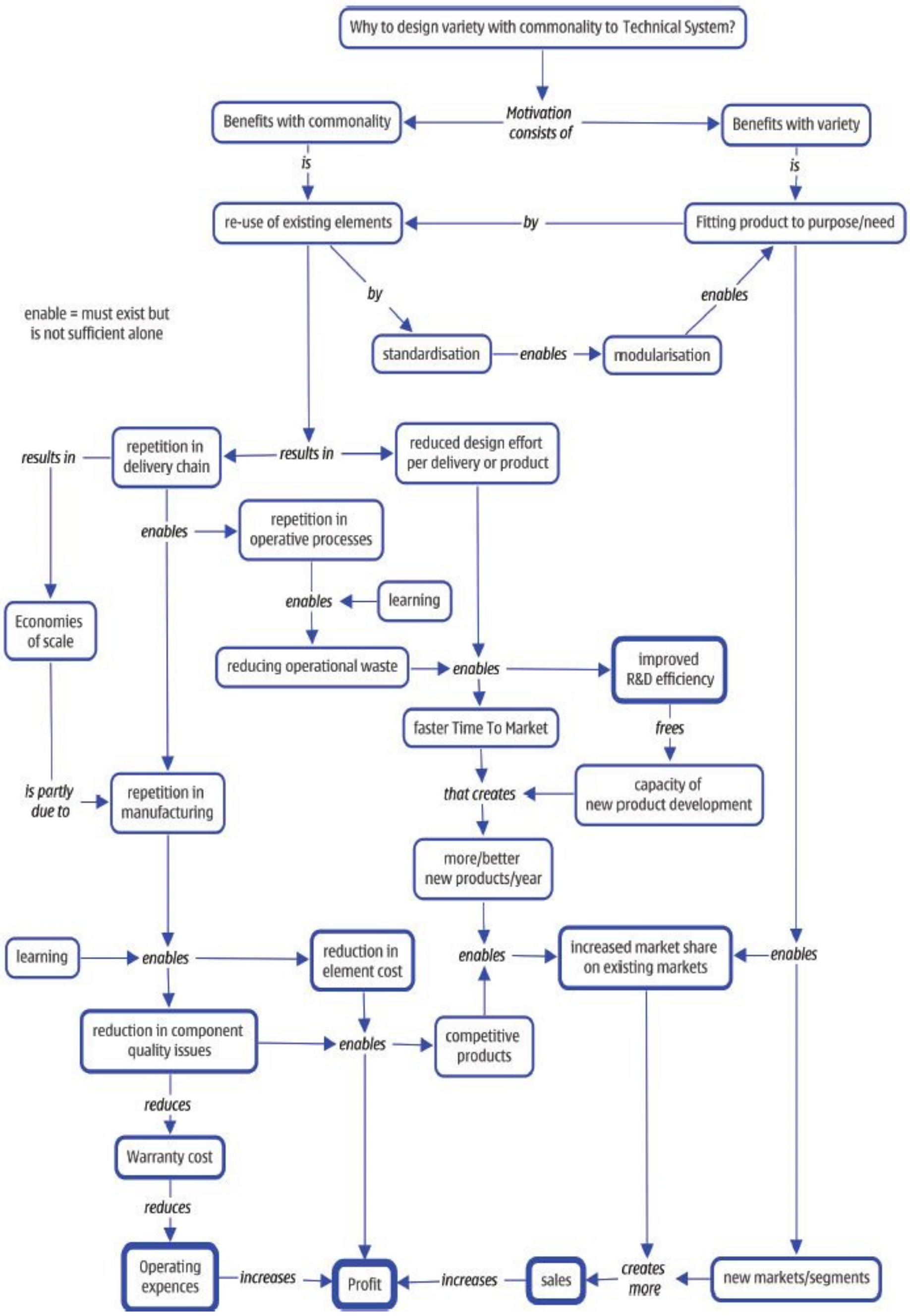

Figure 4.2. Cause-effect chain of the benefits using commonality and variability (Juuti, 2008).

Figure 4.2 shows what effects commonality and variety have on developing and manufacturing. It also lists different business targets and shows what affects them. For example if a company has commonality in their products they can re-use existing elements by using standardization. Standardization enables modularization which ensures that the company has fitting products for different customer needs. This in turn opens new markets, creates more sales and increases the profit.

4.2.2 Company Strategic Landscape

With the use of a CSL framework the relations between product development operations and the production of the company can be clarified. It consists of five elements: product structuring, value chain structuring, strategy structuring, process structuring and organization structuring. It shows that each element has relations to another element (guiding or enabling) and thereby one element cannot be separated and developed individually. CSL highlights the importance of the strategic goals and that the selected solutions in all areas must support them. (Lehtonen, 2007) (Juuti, et al., 2007) An example of a CSL is given in Figure 4.3.

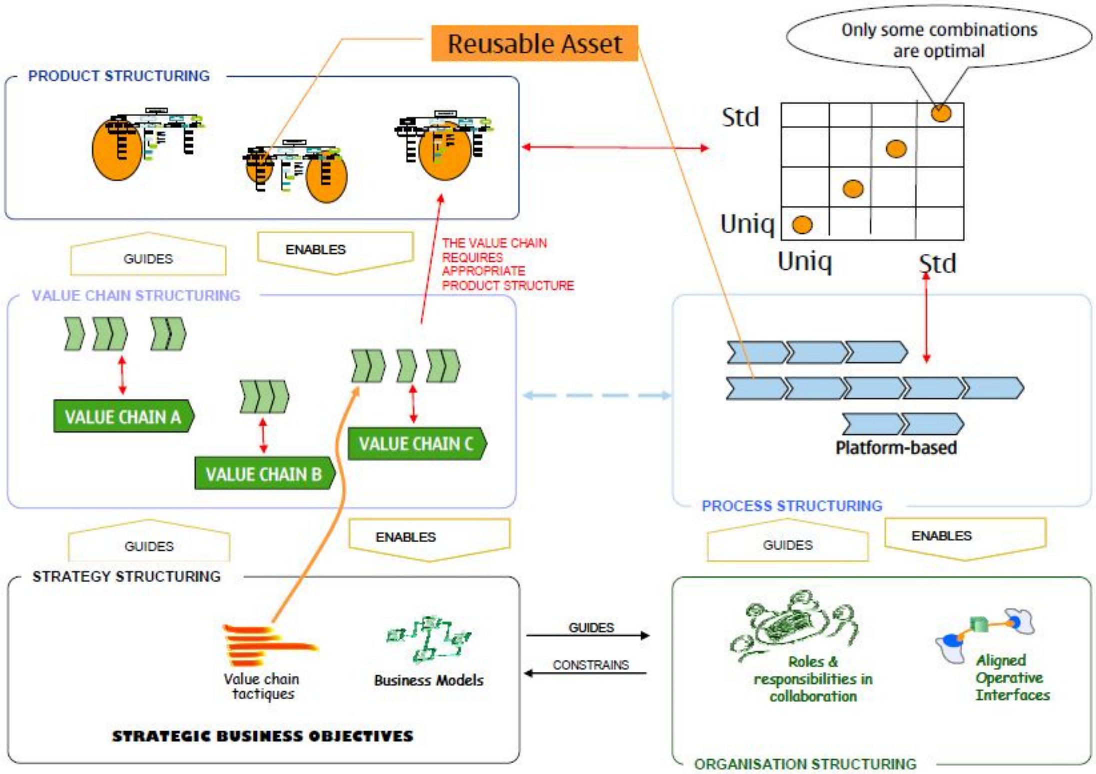

Figure 4.3. A Company Strategic Landscape (Juuti, et al., 2007).

CSL should be used in situations where the objectives for product development are not clear. It describes the main elements of a business environment from a product structuring point of view. In a workshop, with participants from the different company departments, the requirements for the modularization process are gone through and the areas of the CSL framework are defined. The main targets for the modular process can be found by using CSL, because it connects the strategy, value chain, product, process and organization structures. (Pakkanen, 2015)

4.3 Step 2: Generic element model of the Module System

The target of the second step is to define a draft of the module structure. The draft is designed using generic elements and knowledge of existing products. Generic elements are abstract elements which are used as preliminary modules. This step is needed to create a starting point for the development process. The case company defines of which entities their products consists of and these entities are used as generic elements. The generic elements can be, for example, sub-systems, function carriers, assemblies or single parts. (Pakkanen, 2015)

Pakkanen (2015) suggests that one way to fulfill this step is to arrange a workshop-type meeting in which people with strong product knowledge participate. Product knowledge of every product and product variant from the scope of the process is needed. If it comes up, that two or more proposals for generic elements have many commonalities, it should be considered to define only one of them as a generic element. This procedure reduces the risk that the product family will include unnecessary variants. The business objectives defined in the first step should not be forgotten when designing the generic elements and all the results of this step should be documented hierarchically, because in later steps the generic elements are analyzed from a requirement perspective. (Pakkanen, 2015)

The object of this step is to propose generic elements as a starting point for the architecture and product structure of the modular product family. The generic elements are defined in more detail when the BfP proceeds. This step contributes to the set of modules in the Module System, because the generic elements are preliminary modules of the products.

4.4 Step 3: Architecture: generic elements and interfaces

With the results of the second step the general architecture is drafted in the third step. The interfaces of the generic elements are defined by considering how the different elements are connected to each other and how they are located within the product. With well-defined interfaces it is possible that in a situation where the product family doesn't satisfy all customer needs anymore, a new element can be introduced to the product family. The new element can be designed as a unique single purpose element or it can be a new module for the product family if several customers require it. (Pakkanen, 2015)

The relations between the generic elements have to be clarified and for that matrix tools such as the DSM (chapter 3.3.1) can be used. With the help of DSM generic elements are listed in a table and the relations between them are analyzed from an interface perspective. An example of this is given in Figure 4.4.

DSM for interface recognition	Generic element 1	Generic element 2	Generic element 3	Generic element 4	Generic element 5
Generic element 1					
Generic element 2	x				
Generic element 3	x	x			
Generic element 4		x			
Generic element 5			x		

Figure 4.4. An example of a DSM matrix. In this example, for instance, generic element 1 has an interface with generic element 2 and 3. (Pakkanen, 2015)

Pakkanen (2015) states that computer-aided design (CAD) tools could probably not be used in this step because accurately designed product elements describing the final structure are unlikely yet available in this step. Because of the abstract nature of the generic elements traditional office tools can be used in this step instead of or in addition to matrix tools.

In this step information of the generic elements is used to identify the interfaces between different generic elements and it can be considered as a starting point for the designing of interfaces. As in the earlier steps, workshop-type working is also recommended in this step. The results from this step are later on used in step 7 to design modules and interfaces in more detail. The contribution of this step to the Module System is to the set of modules, interfaces and architecture. (Pakkanen, 2015)

4.5 Step 4: Target setting based on customer environment

In this step the customer environment is studied. Because the BfP focuses on existing product designs, there are old products that have been produced and delivered and they had to fulfill some customer requirements. One problem is that some of these old customer requirements may be outdated and are not needed anymore. Therefore it is suggested that the customer environment and the customer needs are reanalyzed in the BfP. The main aim of this step is to define valid customer requirements for the designing of a modular product family. (Pakkanen, 2015)

Lehtonen et al. (2011) used the so-called Gripen method for analyzing the customer requirements. It is a method that was used for realizing the product structure and configuration of Scania trucks. In the beginning of this method, the customer's process is defined, in other words, what the customer is doing with the product. The process could be, for example, lifting tree trunks on trucks. Some key questions have to be formed to define the customer's process and preferred ways to work. Pakkanen (2015) suggests the following questions for defining the requirements from a customer perspective with the focus on variability issues:

- What kind of process can be recognized in which the customers use the company's products (products which are chosen as a starting point in the BfP)?
- What kind of generic process steps and segmentation can be identified from the way in which customers use products?
- What kind of alternative parameters or options, that have an effect on the definition of the product, are related in each process step?
- Are there any other issues or preferred ways of working that cause the need for different products or product options?

This method can be used for segmenting similar variety needs of technical solutions to groups. These groups and solutions have to meet the requirements of a certain customer segment. The Gripen method suggests selling larger assemblies or solutions, instead of individual components. The reason for this is that it is easier to be sure of the compatibility of a larger assembly, than correct functioning of a significant amount of single parts. Using the Gripen method it is possible to develop unnecessary variants and this should be avoided. One reason for the creation of unnecessary variants is the fact, that it is usually easier to define two solutions than one which fits the requirements. This issue is discussed more in later steps. One focus of this step should be to move away from product orientation into analyzing variability from customer perspective. One way to do that is by giving up on product names and naming products based on configurations. (Lehtonen, et al., 2011)

For this step knowledge of the customers is needed and therefore it would be wise that at least the sales team participates in this step. The results of this step describe how the customers work and use their products. The results of this step contribute to the partitioning logic of the Module System, because customer environment has to be considered when designing the structure of the modular product family. If they are not considered, there is a risk that the benefits of modularity are not achieved. (Pakkanen, 2015)

4.6 Step 5: Preliminary product family description

The basis of the product family is further developed in this step and the possibilities for part and assembly standardization are analyzed. One object of this step is to find the minimum quantity of variations that fulfill the customer requirements. For the describing of a product family Harlou (2006) uses a tool called Product Family Master Plan (PFMP). The PFMP includes three views of the product family: customer view, engineering view and part view. The customer view should show the variety from a market point of view, the engineering view should describe the organ structure of the product family and the part view should describe the physical entities of the product family. The original PFMP approach used by Harlou is slightly modified to suit the BfP better. In the BfP the customer view includes the main customer needs that drive the need for variability in the product. Harlou’s engineering view focuses on organs, but in the BfP these are replaced with generic elements. Figure 4.5 shows an example of the result of a PFMP workshop. (Lehtonen, et al., 2011) (Pakkanen, 2015) (Harlou, 2006)

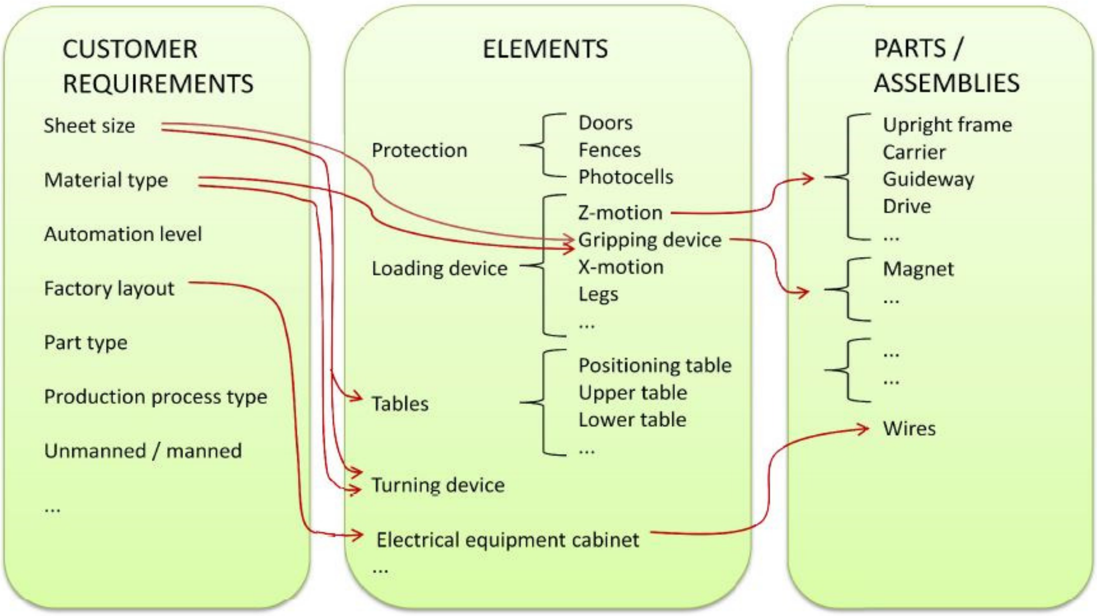

Figure 4.5. Example of relations between customer, element and part view in PFMP (Lehtonen, et al., 2011).

To fulfill the PFMP workshop, the generic elements from the second step of BfP should be listed in the middle of the template as shown in Figure 4.5. The customer requirements studied in step 4 of the BfP are listed on the left side and the parts and assemblies related to the generic elements are listed on the right side. There are two possibilities to continue, first analyze the relations between the generic elements and the customer needs or analyze first the relations between the generic elements and the parts and assemblies.

Analyzing the relations between customer needs and generic elements is done by going through every customer requirement related to variability and drawing a line from it to the generic element that it relates to. If there are some generic elements that are not linked to any customer requirement, these generic elements might be good for standardization (Pakkanen, 2015).

The same kind of analysis is done for the relations between generic elements and parts and assemblies. After the generic elements are linked to the parts and assemblies which have a relation with them, a visible path is formed from the customer requirements to the parts and assemblies as demonstrated with red arrows in Figure 4.5. The relation mapping between the customer requirements, generic elements and parts and assemblies could provide important information for the company. It shows for example if multiple solutions for almost similar customer needs exist. Every variant part or module should be linked to a specific customer requirement which justifies the variation. There might be some exceptions to that rule because of the company's own process. (Pakkanen, 2015)

A good candidate for a module is an element that consists of a set of parts that could be formed for a small amount of standard bill of materials (BOM). Theses BOMs can be defined as modules and variation is achieved by selecting a suitable module, in other words, standard BOM, for the product in the sales-delivery process. If a large amount of the parts of an element could be standardized and only a minor part varies, it could be a configurable element. But there had to be a large base unit, which would be a standard module. (Lehtonen, et al., 2011) (Pakkanen, 2015)

If an element can't be formed from standard BOMs, large modifications are needed before it can be considered as a module. Some suggestions for those situations are dividing the element further, changing the element division or changing the technical solution. If none of these modifications help to find a standardized part set, this feature could be considered to be a unique part which is not part of the product family. One way to improve the commonality in the product family is to use same parts and assemblies in generic elements, which as a whole serve different functions. These parts and assemblies can be found during this step. (Pakkanen, 2015)

To conclude, results of this step give a clear view over the possibilities to add more commonality to the existing products and define the minimum number of variation needed to fulfill all the customer requirements. The structure of the preliminary product family is described with relations between customer, generic element and part and assembly views. This step contributes to the partitioning logic, set of modules and configuration knowledge of the Module System. (Pakkanen, 2015)

4.7 Step 6: Configuration knowledge: generic elements and customer needs

In this step the main focus is on the preliminary configuration knowledge. The relations between generic elements and customer requirements that cause the need for variety are pointed out using a modified version of the so called K- & V-Matrix method.

Configuration knowledge consists of the knowledge that is needed to design a variant product according to customer requirements and the restrictions given by the product itself. In other words it is the knowledge about the possible variants of products and the customer requirements that can be fulfilled with them. (Puls, et al., 2002)

One way to describe configuration knowledge is to use the K- & V-Matrix method. It was developed at the Product Design Centre at the ETH Zürich for this purpose. It is based on two kinds of matrices, the K-Matrix (configuration matrix, “Konfigurationsmatrix” in German) and the V-Matrix (compatibility matrix, “Verträglichkeitsmatrix” in German). The method consists of four components. The *customer view* is a functional description of the product with relevant properties for the customer and it is used during the sales process. The *technical view* describes the modules of the product. The matrix fields of the *K-Matrix* represent the mapping between the customer and the technical view. The matrix fields of the *V-Matrix* describe the compatibilities of the properties with each other of both views of the product. The relations in K-Matrix are marked using only yes (there is a relation) or no (there is no relation) type of markings. (Bongulielmi, et al., 2003) (Pakkanen, 2015) (Puls, et al., 2002)

For this step of the BfP the use of a modified version of the K-Matrix is suggested by Pakkanen (2015). The technical view is not yet defined in detail in this step of the process and therefore more diverse types of relations can be used than yes or no. Pakkanen suggest the following types of relations to be used:

- Customer need excludes a generic element option.
- Customer need might have an effect on the generic element option.
- The generic element option is needed to realize customer need.
- Customer need does not affect the generic element option.

The aim of this step is to define relations between generic elements and customer needs and that can be achieved, for example, by using a K-Matrix shown in Figure 4.6. The generic elements and customer requirements that need to be considered from a variation perspective are organized by using this kind of matrices. In this step the technical view is not yet defined in detail and therefore it is sufficient to analyze only the relations between the generic elements and customer need groups to get an overview of the variation reasoning of the product family. This matrix is also used in the later steps to represent the final configuration knowledge, when the technical view is designed in more detail. So generic elements and their type can be added to the matrix and the relations can be defined in more detail. (Pakkanen, 2015)

Modified K-Matrix (Configuration matrix)

(1) Customer need excludes a generic element option.
(2) Customer need might have an effect to the generic element option.
(3) Generic element option is needed to realise customer need.
(empty cell) Customer need does not effect on the generic option.

GENERIC ELEMENTS	CONTENT AND TYPE OF GENERIC ELEMENTS	CUSTOMER NEEDS	Customer need group 1	Customer need 1.1	Customer need 1.2	Customer need 1.3	Customer need group 2	Customer need 2.1	Customer need 2.2	Customer need group 3	Customer need 3.1	Customer need 3.2	Customer need 3.3	Customer need 3.4	Customer need 3.5	Customer need group 4	...
Generic element 1																	
Generic element 2										3						3	
Generic element 3			3				3			3						3	
Generic element 4							3										

Figure 4.6. Example of a modified K-Matrix which can be used in the BfP (Pakkanen, 2015).

The results of this step show which generic element has a relation with a certain customer need. In step 7 (modules and interfaces) these results are used when defining the solutions for the generic elements and in step 8 (module variants and customer needs) the modules among other elements are added to the matrix to demonstrate the final configuration knowledge. In the Module System this step contributes to the design information element of configuration knowledge. (Pakkanen, 2015)

4.8 Step 7: Modular architecture: modules and interfaces

In the seventh step the structure of the modular product family is defined in more detail. The aim is to define the product family architecture including modules and their interfaces. Modular architecture enables major benefits for configuration and that is one reason why this step is important. Pakkanen suggests, that an issue to focus on in this step is how to define generic element types from product structuring strategy viewpoint considering the effect of customer needs and business objectives to each generic element. The second issue to focus on should be the definition of interfaces between the elements of the architecture. (Pakkanen, 2015)

In step 3 a generic architecture was formed and now different product element types have to be recognized from it. Juuti (2008) explains that there are several different product structure types. Generic elements can be standard, modular/configurable or one-of-a-kind. Standard elements are the same in every variant of the product family. Modular elements include standardized variant options. One-of-a-kind, in other words, unique elements are used to satisfy a specific customer need, if standard or modular elements cannot be defined for that area. The use of one-of-a-kind elements should be avoided, because they have to be designed separately in each product delivery case. The objective is to recognize different elements from the architecture as shown in Figure 4.7. (Juuti, 2008) (Pakkanen, 2015)

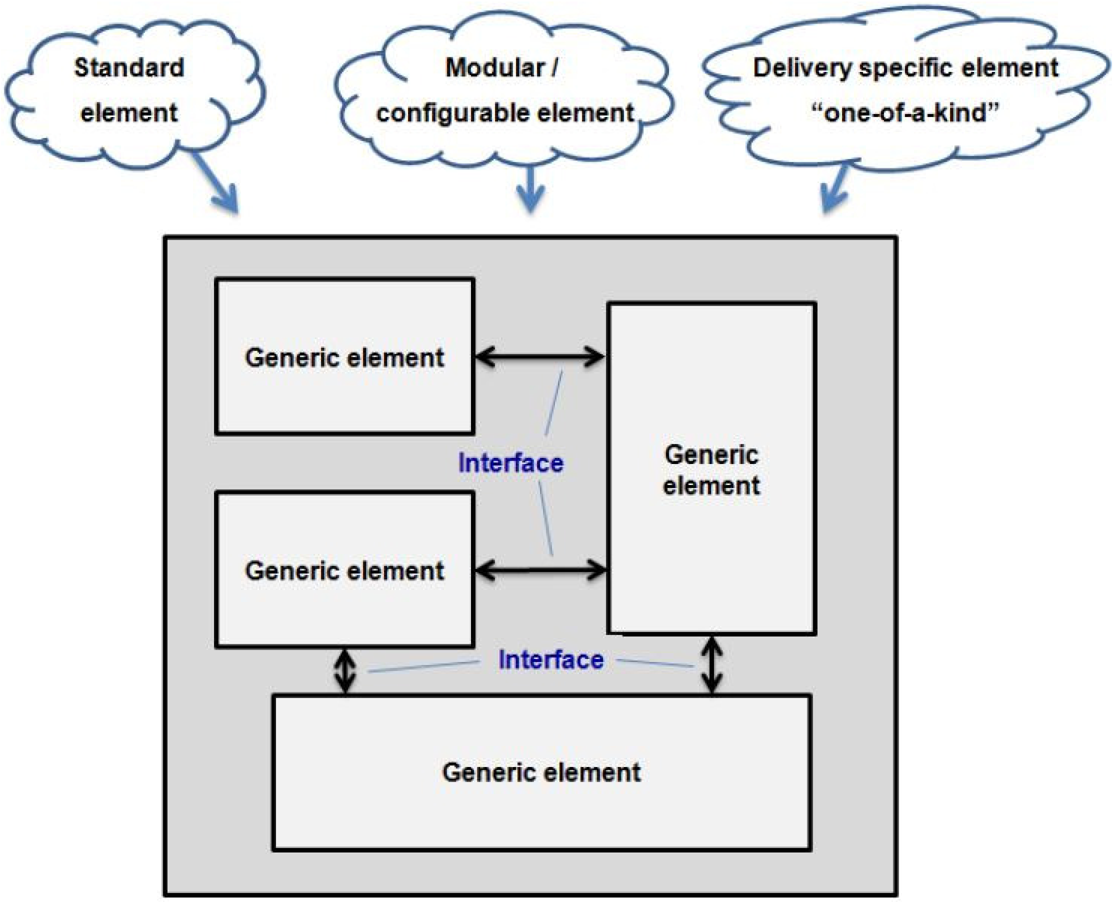

Figure 4.7. The generic elements have to be defined in more detail. The aim is to define which of them are standard, modular/configurable or delivery specific elements. (Pakkanen, 2015)

Variable products should include standard solutions as much as possible and only a minimum number of interchangeable standardized modules, if there cannot be used one standardized solution from a variation-need perspective. To enable effective variation the interfaces between the modules should also be standardized. In this step the standard elements are recognized by using the preliminary configuration knowledge and description of the product family. Also the connection between customer needs that create need for variation and the business objectives that were discussed earlier have to be considered. If there is no need for variation in the area of a generic element, the generic element could be a standard element. That would mean that the same element could be used in the entire product family. (Pakkanen, 2015)

When the standard elements are defined, the next step is to focus on the generic elements that include a need for variation. There should be found a minimum number of alternative standardized modules, which fulfill the requirements for the product family for generic elements which involve variation needs from business or customer environment. Clear objectives are important during the designing of modules and they should also include variation needs, because so the minimum requirements that the product family have to fulfill are defined. The variation needs defined in step 4 have to be relevant for designing. The importance of a variation need can be analyzed, for instance, by studying the needs in relation to realized product deliveries. Thus it might not be reasonable to design re-usable and interchangeable modules for business areas, which have low sales potential, if the designing of these kinds of modules is more complex than the designing of delivery-specific elements for each case. Also when designing re-usable elements the use of these elements in other variants have to be determined. This can, for instance, increase the development costs of the element because multiple issues related to the element have to be considered. (Pakkanen, 2015)

It could be technically possible to design a single standard solution for a given variation need, but there might be a risk that this kind of element could be too expensive. This standard element would include all potential solutions and adaption properties for every variation need, but only some of them would be used in a specific customer application. This kind of element could be harmful for the business, because of the wide set of properties it would be expensive and customers could ask why they need to pay for properties they are not using. In a situation where the variation needs cannot be fulfilled by using a standard solution the use of interchangeable modules or unique elements should be considered. (Pakkanen, 2015)

According to Pakkanen (2015) an approach for defining of commonality indices developed by Martin & Ishii (1997) can be used to estimate the quality of existing part sets by studying how many different customer requirements the parts fit. This kind of index shows how well the design uses standardized parts. In the worst situation every variation need is covered with a different part. If the same parts and solutions could be used in different variations it would provide a better situation. As discussed earlier, one goal of the BfP is to increase the re-use of parts in the sales-delivery process. The reasonable number of parts changes in every case, because it is affected by what kind of customer needs the same product family has to fulfill and what kind of possibilities there are for using standardized parts. (Pakkanen, 2015)

All the generic elements cannot necessarily be specified as standard parts or be defined as interchangeable modules based on standardization. These generic elements are defined as unique elements. Even though the unique elements could use standardized interfaces it must be remembered that by using these kinds of elements the benefits of re-use are not achieved. The use of unique elements can be justified, for instance, in situations where a difficult variation need exists in which properties of the technical solution are widespread and typical variation reasoning cannot be defined. (Pakkanen, 2015)

The designing of interfaces is an important task in the design process of a modular product family. It is suggested that interfaces should be standardized. Standardized interfaces enable interchangeability and independence of the modules. Important interfaces can be recognized by drafting of product or product family architecture. In the BfP interfaces should be defined so that the definition forms an agreement between two or more elements. This means that all the interfaces must be defined in the modular product family architecture. The interface definition includes all the necessary information that is needed to design suitable elements which use the same interface. The interface agreement also explains what kind of restrictions modules have to fulfill. (Pakkanen, 2015)

In an application where space is a critical design criterion, it could be wise to define areas for the product of which the variants dedicated for each section are not allowed to cross. In doing so, it would give the designers clear rules for avoiding possible disturbances of a module in regard to other sections of the product. The strictness of space limitation must be considered and the rationality of restrictions of this kind must be analyzed in each case. (Pakkanen, 2015)

Pakkanen (2015) also suggest that there should be clear ownership of the elements and interfaces. If the elements and interfaces are not managed after the BfP and there is no clear ownership, there is a risk that the modular architecture weakens during time and the benefits of re-use are lost.

In conclusion, this step aims on providing the modular architecture of the product family. The architecture defines what kind of elements and interfaces are used in the product family. Therefore this step contributes to the set of modules, interfaces and architecture elements of the Module System. The results of this step are needed in the clarification of the final configuration knowledge which is needed to define product variants efficiently based on customer requirements (step 8). Results are also needed in product family documentation (step 9) and in the business impact analysis (step 10). (Pakkanen, 2015)

4.9 Step 8: Configuration knowledge: module variants and customer needs

In step 6 the configuration knowledge was defined in regard to generic elements and customer needs. In step 8 the configuration knowledge is defined using actual solutions gained from the previous step. It is easier to define a product variant later in the sales-delivery process with well defined configuration knowledge. The aim of this step is to produce a documentation that explains clearly which technical solutions and customer needs match. (Pakkanen, 2015)

Pakkanen (2015) suggests using the same modified K-Matrix from step 6 also in this step. In step 6 the generic elements were defined and the information is used in this step as input. The content and type of generic elements have to be added to the previously defined K-Matrix. The K-Matrix should also show the relations between the elements and the customer requirements. A template and example results for this step are given in Figure 4.8.

Modified K-Matrix (Configuration matrix)

(**1**) Customer need excludes a generic element option.
(**2**) Customer need might have an effect to the generic element option.
(**3**) Generic element option is needed to realise customer need.
(**empty cell**) Customer need does not effect on the generic option.

GENERIC ELEMENTS	CONTENT AND TYPE OF GENERIC ELEMENTS	CUSTOMER NEEDS	Customer need group 1	Customer need 1.1	Customer need 1.2	Customer need 1.3	Customer need group 2	Customer need 2.1	Customer need 2.2	Customer need group 3	Customer need 3.1	Customer need 3.2	Customer need 3.3	Customer need 3.4	Customer need 3.5	Customer need group 4	...
Generic element 1																	
	Solution 1.1 (Standard element)																
Generic element 2										3						3	
	Solution 2.1 (Modular element)										3	3		3			
	Solution 2.2 (Modular element)												3				
	Solution 2.3 (Modular element)														3		
Generic element 3			3				3			3						3	
	Unique element			3	3	3		3	3		3	3	3	3	3		
Generic element 4							3										
	...																

Figure 4.8. An updated version of the K-Matrix used in step 6, which includes the content and type of the generic elements. (Pakkanen, 2015)

In this modified K-Matrix the relations between customer needs and solution are marked with the same numbers as explained in step 6. The description of the relations is given in the top left corner of Figure 4.8. The matrix shown in Figure 4.8 doesn't explain why a relation is a certain type. This kind of information could be important in the future when the product family is developed further and it is suggested to add comments to the relation fields that explain the reason for a specific relation. (Pakkanen, 2015)

The compatibilities between generic elements and their content can also be analyzed in this step. For this Pakkanen (2015) suggests using, for example, the V-Matrix discussed by Bongulielmi (2003). Both the rows and columns would include generic elements and their content and matching combinations would be defined in the matrix. For building a configurator, knowledge about compatible customer needs is required. This means, that if a customer chooses some options, it could be that these options exclude the possibility to choose certain other options. Figure 4.9 shows an example of a V-Matrix that includes generic elements and their content. A V-Matrix like that could also be used to analyze the compatibilities between different customer needs.

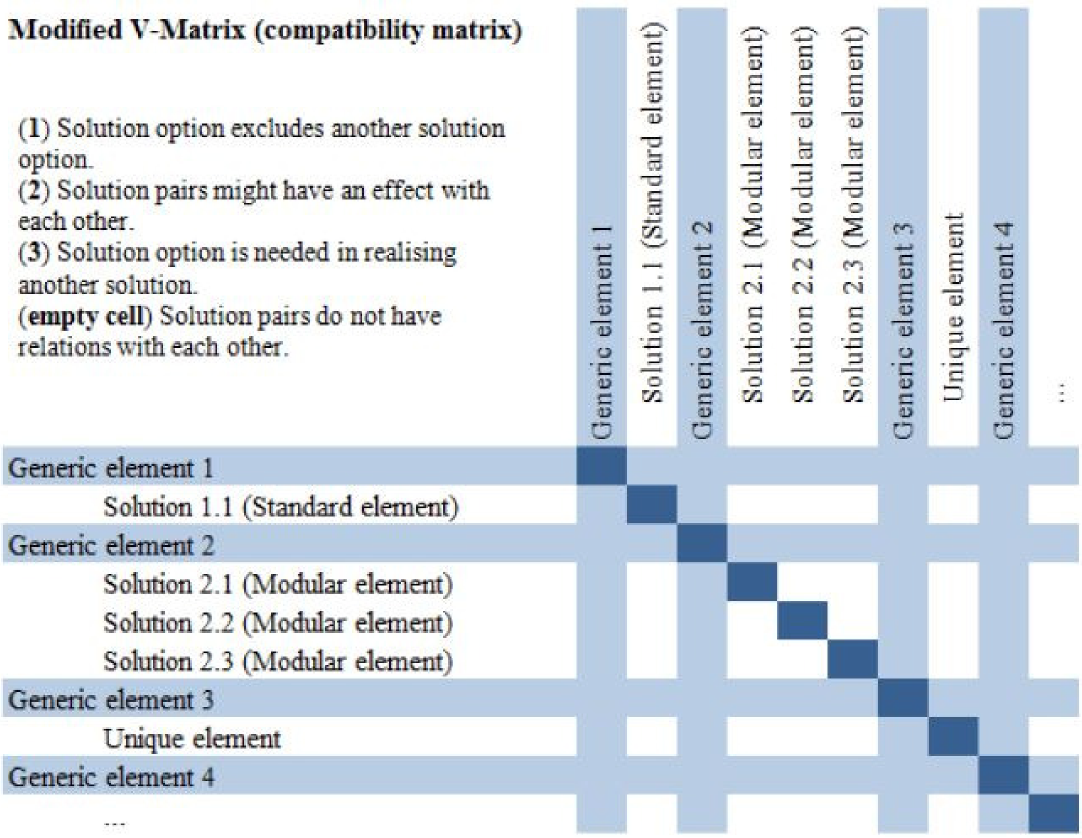

Figure 4.9. An example of a modified V-Matrix for the analyzing of compatibilities between generic elements and their content. (Pakkanen, 2015)

The results from this step are needed in the documentation of the product family (step 9) and it can also be used in the analysis of the business impacts (step 10). The results of this step show, for example, which module variants are compatible for certain customer needs. This step also shows how different solutions relate to each other and how customer needs affect each other. This step contributes to the configuration knowledge of the Module System. (Pakkanen, 2015)

4.10 Step 9: Product family documentation

In the ninth step of the BfP the product family is documented. It aims at describing the content of the product family and explaining which customer needs each element corresponds to. This step needs the results of the previous steps as input information. (Pakkanen, 2015)

Lehtonen et al. created a description method called Product Structuring Blue Print (PSBP). PSBP shows how elements are related in assemblies, how modules include assemblies, how modules are realized, and what customer requirement is connected to each module. It also gives a solution on how to make product structuring decisions. Figure 4.10 shows an example of a PSBP. (Lehtonen, et al., 2011)

Figure 4.10. An example of a PSBP showing the product structuring. (Pakkanen, 2015)

The PSBP explains the reasoning of the product family. In the example PSBP in Figure 4.10 the leftmost side describes the product family. In the next section to the right the generic elements are described. After that the solution principles that describe how generic elements are realized are shown. On the right hand side the variation needs from the customer perspective are linked to the corresponding solutions. In this model of the PSBP three different solution principles for elements are used: standard, modular or delivery-specific. The example PSBP shows that realized generic elements can include several types of solution principles, for example, Generic Element 3 consists of solution Lambda, Mu, Xi and Nu. Lambda and Mu are modular elements, Xi is a standard element and Nu is a delivery specific element. Customer needs 5 and 6 relate to these solutions. (Pakkanen, 2015)

This step provides a clear documentation of the product family. It makes the reasoning of the content of the product family visible and can so be helpful in the support of design work and for increasing design re-use. This kind of documentation helps also the re-designing of a product family, if the product family is developed further because of technological evolution or changed variation needs. This step contributes to the partitioning logic of the Module System. (Pakkanen, 2015)

4.11 Step 10: Business impact analysis

In the last step of the BfP a business impact analysis is carried out. In order to estimate the business effects or potential of the designed product family this kind of analysis is important. For this analysis Pakkanen (2015) created a model of business impacts of modularization shown in Figure 4.11.

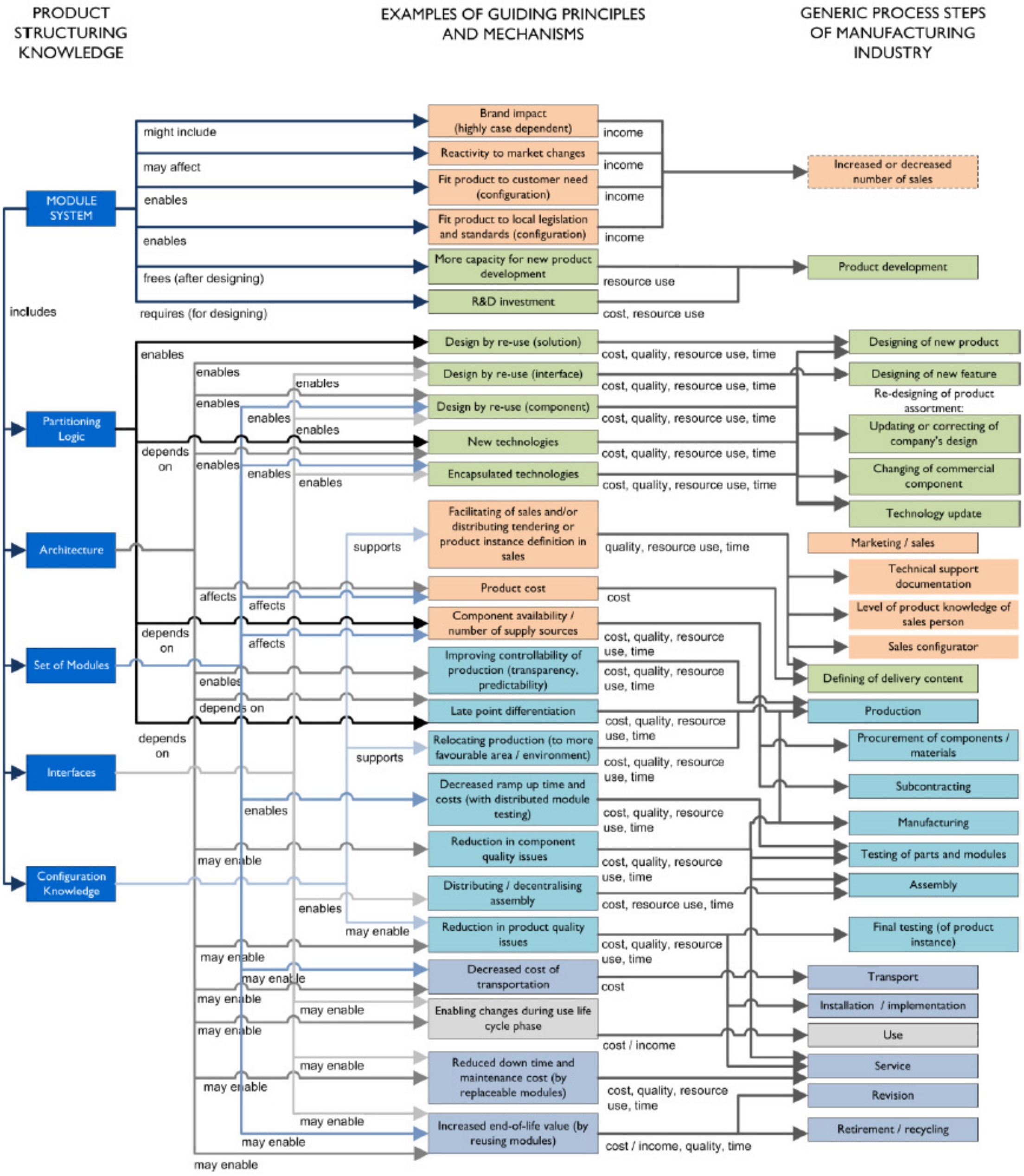

Figure 4.11. Model for estimating business impacts of the Module System. (Pakkanen, 2015)

The left side of Figure 4.11 shows the product structuring knowledge. It shows what effects the whole Module System has and also the effects of each of the elements of the

Module System: partitioning logic, architecture, set of modules, interfaces and configuration knowledge.

The middle of the Figure 4.11 shows examples of guiding principles and mechanisms. These principles describe the possible objectives, phenomena and problems related to modularization. They have similarities with the module drivers in MFD discussed in chapter 3.3.3. Relations between the elements of the Module System and the guiding principles are also demonstrated in Figure 4.11. They describe which element of the Module system might have an effect on which guiding principle and mechanisms. (Pakkanen, 2015)

On the right hand side of the Figure 4.11 the generic process steps of the manufacturing industry are shown. These process steps can include, for example, product development, marketing and sales, production, transportation, installation and implementation, use, service, revision and retirement / recycling.(Pakkanen, 2015)

The top of the Figure 4.11 shows the Module System and the guiding principles and mechanisms related to it. It also shows which process steps are affected by it. The Module System may affect brand impact and reactivity to market changes. It enables the company to fit products to customer needs and fit products to local legislation and standards. It also frees more capacity for new product development and requires R&D investments. These mechanisms affect the number of sales and product development.

Partitioning logic enables design by re-use (solution). It depends on new technologies, component availability / number of supply sources and late point differentiation. These mechanisms affect designing and production.

Architecture enables design by re-use (interface and component), new technologies and improving controllability of production. It affects production costs and it depends on late point differentiation. It may also enable reduction in component quality issues, reduction in product quality issues, decreased cost of transportation, allowing changes during the lifecycle of the product, reduced down time and maintenance cost by replaceable modules and increased end-of-life value by reusing modules. These guiding principles and mechanisms affect at least the product development, marketing / sales, production, logistics, installation, use, service and recycling.

Set of modules enables design re-use (component), encapsulated technologies and decreased ramp up time and costs with distributed module testing. It affects product costs and component availability / number of supply sources. It may also enable decreased cost of transportation and increased end-of-life value by reusing modules. These mechanisms affect designing aspects, defining of delivery content, production, transport, revision and retirement / recycling.

Interfaces enable design by re-use (interface and component), new technologies, encapsulated technologies and distributing / decentralizing assembly. It also may enable allowing changes during the lifecycle of the product, reduced down time and maintenance cost by replaceable modules and increased end-of-life value by reusing modules. These have an effect on designing, assembly, use, service, revision and retirement / recycling.

Configuration knowledge supports the facilitating of sales and/or distributing tendering or product instance definition in sales and relocating production to more favorable areas or environments. It may also enable reduction in product quality issues. These mechanism and guiding principles affect marketing and sales, defining of delivery content, production, installation and service.

In Figure 4.11 the relations between guiding principles and mechanisms and process steps are described with income, cost, quality, resource use or time. Sometimes it is difficult to estimate these relations in real life cases and therefore some of these relations are only assumptions. These relations are considered in the BfP from an economical perspective. The effects of these relations can either increase or decrease profitability. Cost effects can include, for example, costs of parts and materials or possible needs for equipment investments. Income effects could also be understood as cost issues with increasing profit effects instead of reduction. Quality effects are estimated from a product quality perspective which describes how well the resulting product matches the specifications. Time effects relate to lead time issues. (Pakkanen, 2015)

The results of this step estimate the effects of a successful modular product family development project. It represents the estimate of the largest benefit of the Module System. The review period for the business impact analysis should be long enough so that, for example, possible product revisions later in the product life cycle can also be considered. It is suggested that instead of using absolute values for money it would be wise to use “decades” of money, for example, thousands, tens of thousands, hundreds of thousands, etc. The largest decades are in a dominant role when analyzing the results of this step. Thus the largest decades can be studied in more detail if necessary. It could be, that some areas are not well-enough known for the analysis and therefore it is possible that impacts of some principles and mechanisms are impossible to evaluate. (Pakkanen, 2015)

4.12 Modification of the process

The steps of the BfP are shown in Figure 4.1 in a numerical order. This order of the steps is a suggestion. The order of the steps can be modified to suit the needs of the company better. If the company has information and knowledge to some steps of the BfP before starting the process, it shall be used to start the process and so change the sequence of the steps.

Pakkanen (2015) suggests, for example, the following orders for the process:

a) Modified order of the BfP steps: 1,2,3,4,5,2,3,6,7,8,9,10
b) Modified order of the BfP steps: 1,4,2,3,5,6,7,8,9,10
c) Modified order of the BfP steps: 1,2,3,4,5,6,7,8,10,9

Some steps of the BfP may provide information that cause or suggest a change in earlier steps of the process. For example, it may be recognized in step 5 that the generic element model from step 2 and the architecture from step 3 may need some modifications in order to improve standardization opportunities. For this kind of situations version 'a' may be used. Pakkanen assumes that product-oriented thinking is dominant in design organizations and therefore at the beginning of a product development process there might be desires to begin the discussions related to concrete products directly after the primary goals have been set. Therefore alternative 'b' could be used, in which customer environment from step 4 is studied after business environment from step 1. The business impact analysis from step 10 could also be made before the product family documentation from step 9 as demonstrated in alternative 'c'. The product family documentation doesn't affect the business impact analysis and therefore the order can be changed or they could be made parallel. In addition to changing the order of the steps, the BfP can be modified also by using different methods or approaches in some steps. Some of these alternative approaches were discussed in the earlier chapters. (Pakkanen, 2015)

4.13 Summary of the BfP

In chapter 4 of this thesis the full Brownfield Process is introduced and discussed. The different steps are explained in detail and the structure of the process is introduced.

Figure 4.12 shows a summary of the relations between different steps of the BfP made by Pakkanen (2015). It shows also the required and resulting design information elements and their relations. For steps 1, 4 and 10 the figure shows also external requirements, because for these steps this kind of external information is highly important.

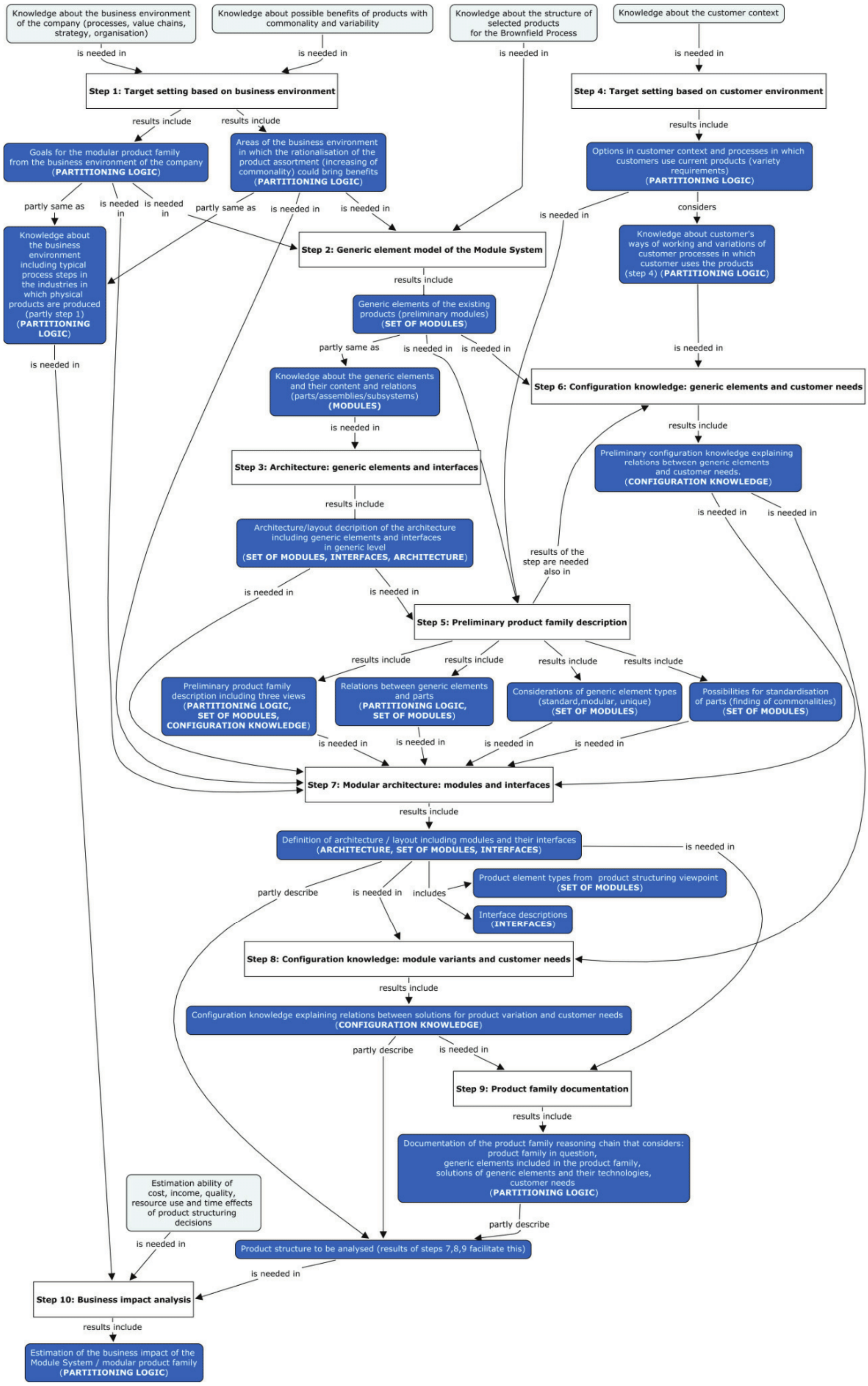

Figure 4.12. Summary of the BfP (Pakkanen, 2015).

5. EXAMPLE CASE

In this chapter the example case is discussed. It describes how the Brownfield Process is implemented in a company for their products and what kind of results could be accomplished. Because of confidentiality reasons all steps could not be discussed in detail in this thesis.

5.1 Overview of the example case

In this case the Brownfield Process is used to make a proposal on how to modularize the current product family of the case company.

In this case steps 1, 2, 3, 4, 5, 7, 9 and 10 of the BfP were used. Because of simple product structure in this case, the steps 6 and 8 were left out of this study. The resulted information of these steps was gained from the other steps.

5.2 Step 1: Target setting based on business environment

Main points of this step:

- Selecting scope
- Target setting by using CSL or cause-and-effect diagram

In the beginning of this step the scope for this case was selected. Because of the time and resource limitations of this thesis only certain cranes of the company could be chosen for the modularity process and only certain structures of these cranes were analyzed. For this study five different cranes from the company's product family were chosen. The cranes are named in this study crane 1,2,3,4 and 5 from the smallest to the heaviest. The study focuses on the base and stabilizer system of these cranes, because that area can be fairly good isolated from the rest of the crane and initial research showed some improvement potential in that area.

As described in chapter 4.2, cause-and-effect chain is suggested to be used in situations in which the company has a common understanding about the benefits that are gained with modular product families. If the objects for product development are unclear the use of CSL is suggested. It was decided to use the cause-and-effect chain in this case. The cause-and-effect chain is shown in Figure 4.2.

Every company tries to make profit, so obviously it is the main target in the long run. But there are different approaches to increase profit. The company's main target was to reduce the invested capital. This can be achieved by reducing part numbers which has an effect on cost savings in development, production, storage and logistics. Additional targets are material cost reduction and lead-time reduction. From the cause-and-effect chain it can be seen, that improved R&D efficiency and reduction in element cost are targets which help to achieve increased market share on existing markets which leads to more sales and thus to more profit. So from the viewpoint of the cause-and-effect chain the main targets are improved R&D efficiency and reduction in element cost.

During this step a survey was sent to a multi-disciplinary group of people working at the company. The list of recipients included members of the marketing, after-sales, product lifetime care and R&D teams. Participants were asked to provide input by naming their critical viewpoints and estimations of the requirements and possible benefits or disadvantages of modular products. The answers of the survey were also used to help the target setting.

5.3 Step 2: Generic element model of the Module System

Main points of this step:

- Define a draft for the module structure

For this step knowledge about existing products is needed and gathering that information was done first. As described earlier the study focuses on the base and stabilizer system. The preliminary module structure was defined using old product solutions as a starting point. The preliminary module structure is as following:

1. Stabilizer leg (two in one system)
2. Stabilizer extension (two in one system)
3. Base (with integrated stabilizer beam)
4. Base (without integrated stabilizer beam)
5. Stabilizer beam
6. Three-point bridge
7. Slewing cylinder
8. Slewing piston
9. Stabilizer extension cylinder

The preliminary module structure is also demonstrated in Figure 5.1. Stabilizer extension cylinder, slewing cylinder and slewing piston are shown in Figure 5.12 and Figure 5.14.

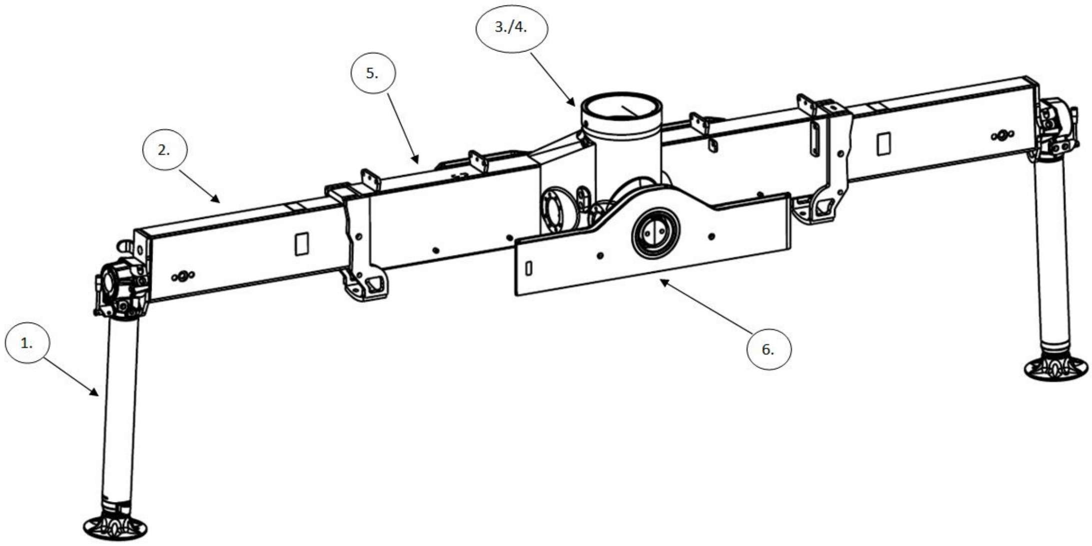

Figure 5.1. Preliminary module structure.

There are two different types of base constructions in this study. The smaller cranes have a casted base housing which is welded onto the stabilizer beam as shown in Figure 5.4. The heavier cranes have a welded base housing and are used with a separate stabilizer beam as shown in Figure 5.5. If casted bases are used, the use of a three-point bridge, part number 6, is also necessary. The heavier cranes using welded bases do not need a three-point bridge. So there are two different combinations of parts depending on which base is used. The smaller cranes use a combination of parts number 1, 2, 3, 6, 7, 8 and 9. The heavier cranes use the parts 1, 2, 4, 5, 7, 8 and 9. The current state of the existing components is analyzed in the following chapters.

5.3.1 Stabilizer leg

Stabilizer legs are used to ensure stability of the crane and truck. In transport position the legs are lifted up and when the crane is operated the legs are extended down to the ground. The stabilizer footplate is the part of the stabilizer system that is in contact with the ground. There are different lengths of stabilizer legs, because the height of the trucks varies.

The products in the study use 5 different stabilizer legs. The differences are dimensions, mechanisms for locking the legs and lifting mechanisms. The two different locking mechanisms for the legs are shown in Figure 5.2 and Figure 5.3.

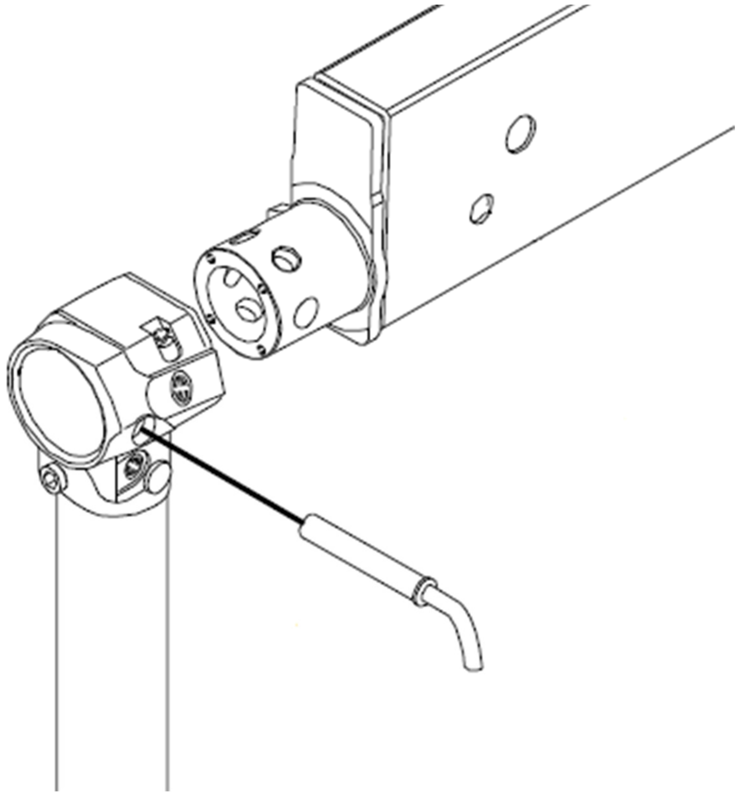

Figure 5.2. Leg locking mechanism A. (Hiab, 2015)

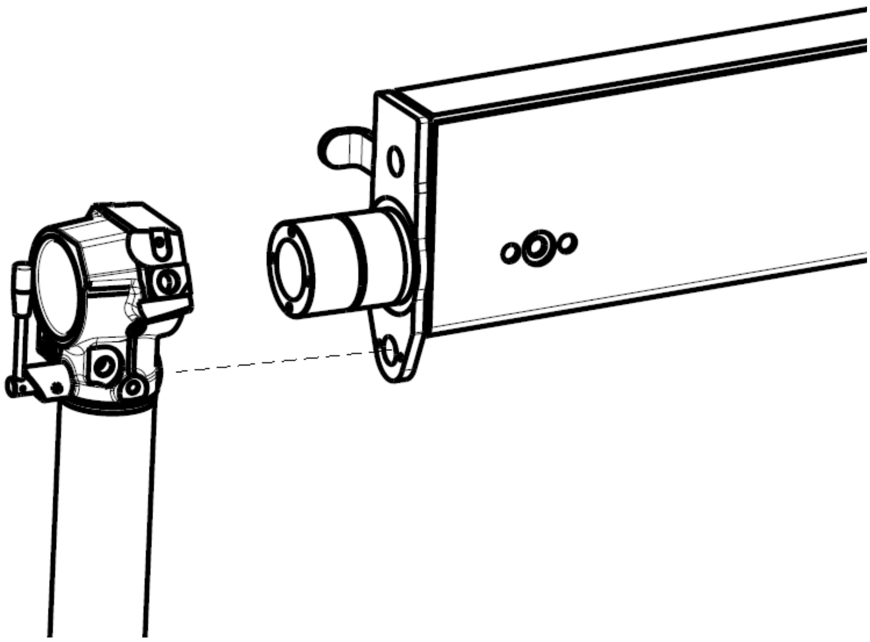

Figure 5.3. Leg locking mechanism B. (Hiab, 2015)

The end of the stabilizer extension in locking mechanism A has holes in it to allow locking in different angles. The locking mechanism B is only used to lock the leg in the down position for operating of the crane.

5.3.2 Stabilizer extension and extension cylinder

Stabilizer extensions are used to change the width of the stabilizer system. The extension cylinder is used for the extension of the legs. There are 15 different stabilizer extensions in this study and 6 different extension cylinders. The main differences of the extensions are the lengths and if the extension is prepared to use the so-called powerlift. The powerlift is a hydraulic lifting system that is used to lift the stabilizer leg up 180° into transport position. If the crane is not equipped with powerlift, the legs can be lifted mechanically using a “lifting plate”.

5.3.3 Stabilizer beam, base and three-point bridge

As previously mentioned, the cranes have two different base constructions. The smaller cranes use casted bases with integrated stabilizer beams and the heavier ones use welded bases with separate beams. The products in this study have 3 different casted bases with integrated stabilizer beams, 2 different three-point bridges, 3 different welded bases and 4 different stabilizer beams for the welded bases. The three-point bridges are used to mount the crane onto the truck.

5.3.4 Slewing piston and cylinder

The slewing system is used to rotate the boom system. Smaller cranes use single-rack slewing and the heavier ones double-rack slewing. The study includes three different slewing pistons and 5 different slewing cylinders.

5.4 Step 3: Architecture: generic elements and interfaces

Main points of this step:

- A starting point for designing of interfaces
- Drafting the architecture of the product in which generic elements and their interfaces are defined

Because of the simple structure of the case example there is no need to use matrix tools like DSM. For this step the interfaces were defined using old drawings. A layout figure was made for the casted base housing and welded base housing variants. These are shown in Figure 5.4 and Figure 5.5.

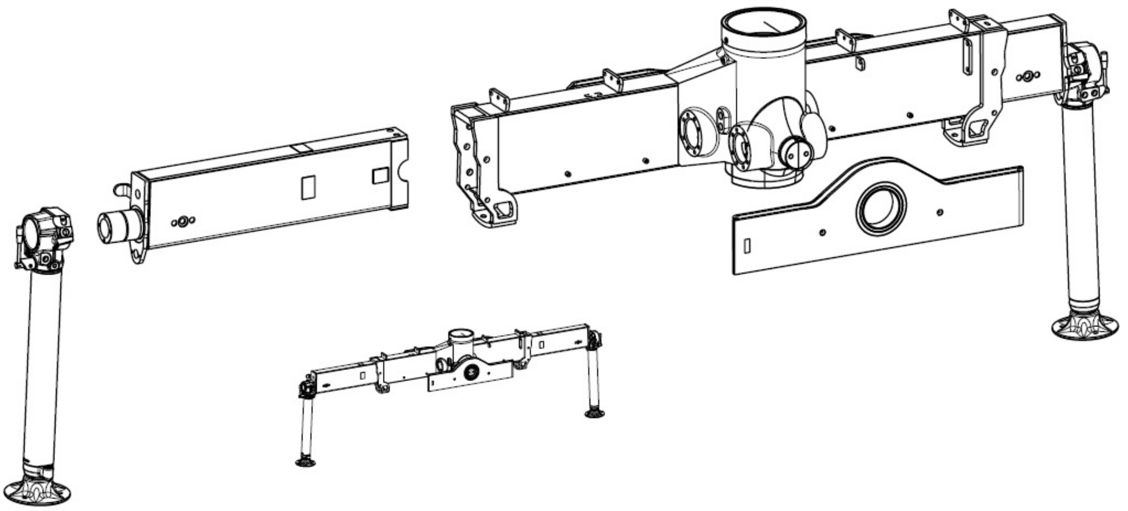

Figure 5.4. Construction of base and stabilizer system with a casted base.

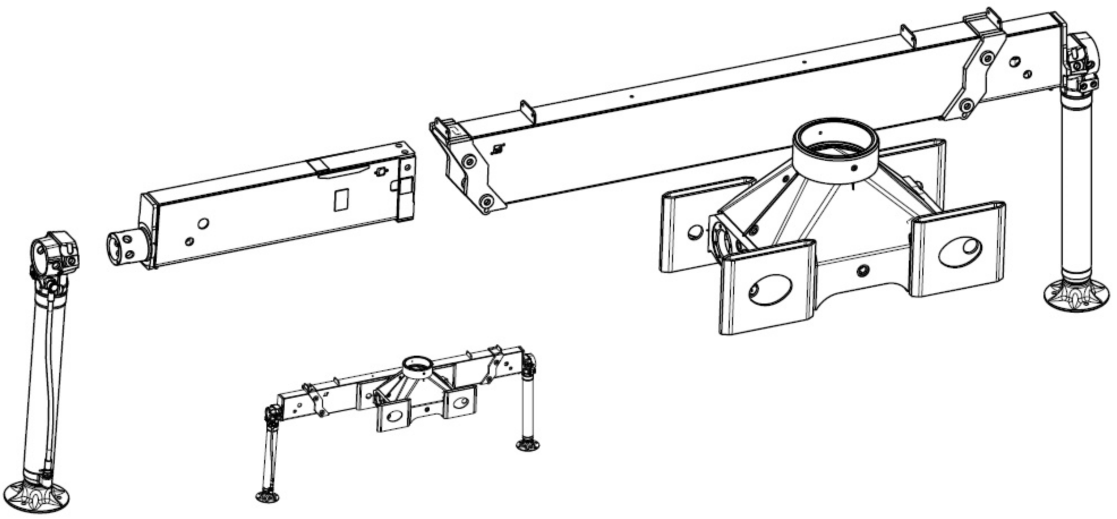

Figure 5.5. Construction of base and stabilizer system with welded base.

Figure 5.6 – Figure 5.10 demonstrate the structure and variation options of the current base and stabilizer system of the cranes in the study. Each color in the drawings represents a different type of part.

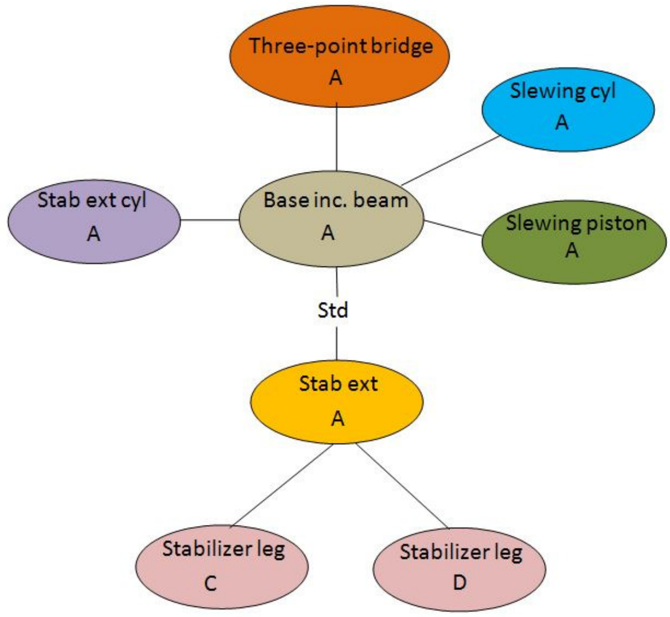

Figure 5.6. Structure of Crane 1. Stab stands for stabilizer, ext stands for extension and cyl stands for cylinder.

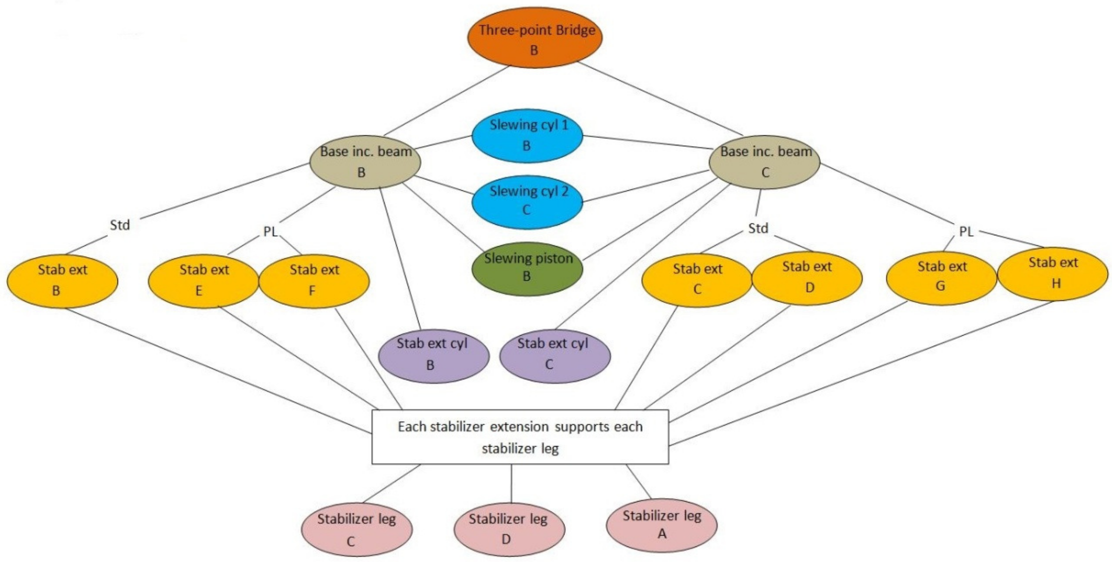

Figure 5.7. Structure of Crane 2. Std stands for standard lifting mechanism and PL stands for powerlift.

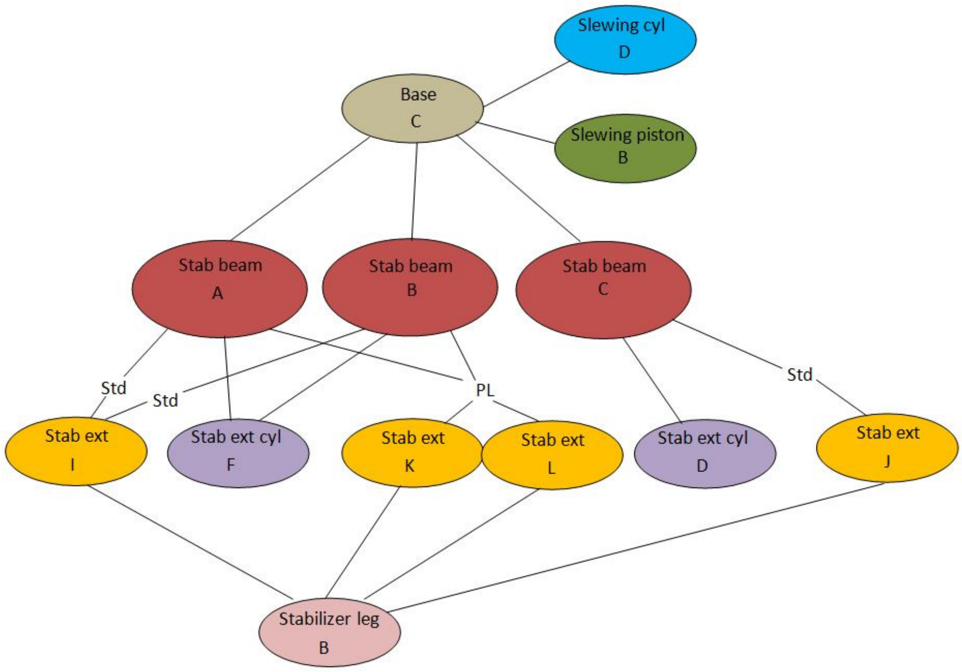

Figure 5.8. Structure of Crane 3.

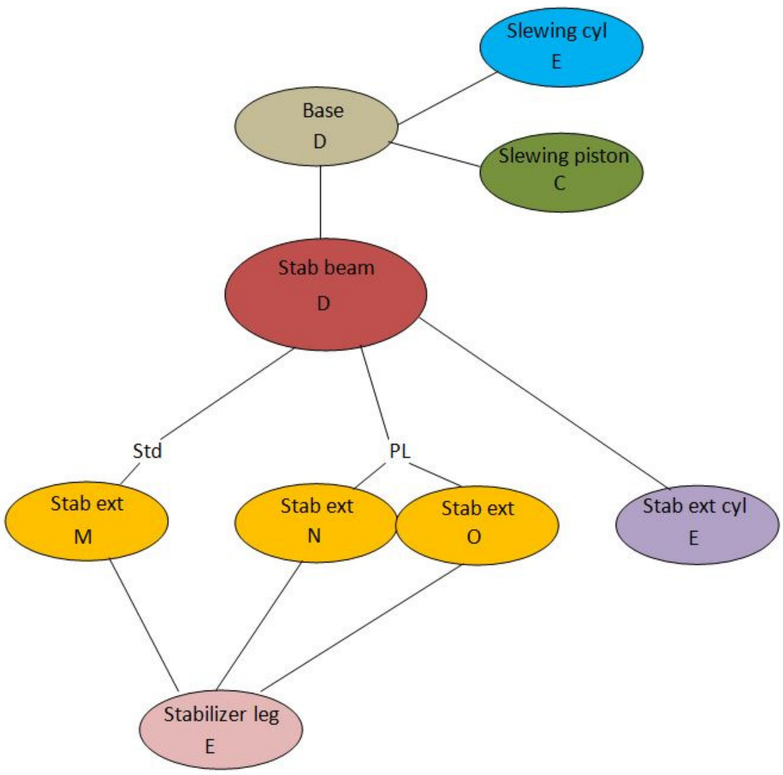

Figure 5.9. Structure of Crane 4.

Figure 5.10. Structure of Crane 5.

The following figures show the interfaces and how each part is connected to the other parts.

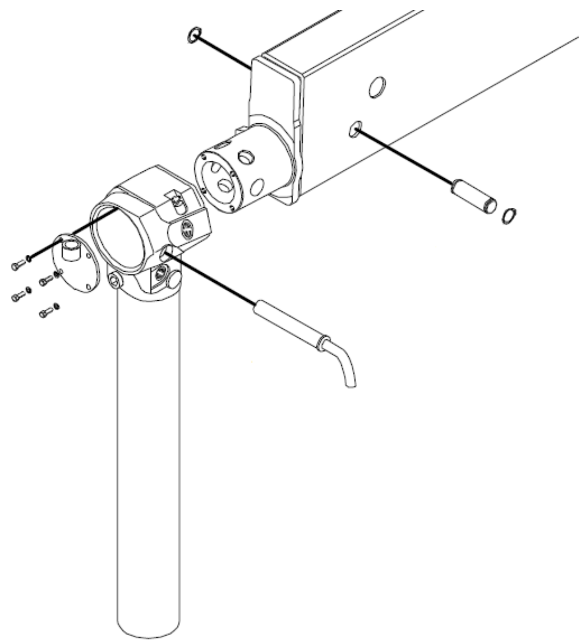

Figure 5.11. Interface between stabilizer leg and stabilizer extension. The stabilizer leg is mounted to the stabilizer extension with screws and a plate. (Hiab, 2015)

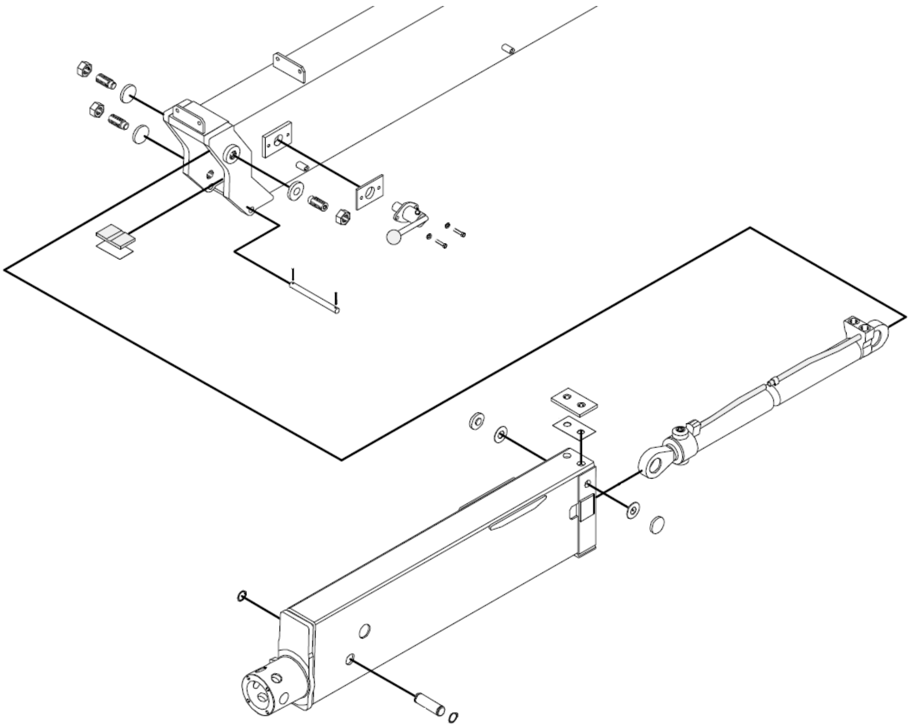

Figure 5.12. Interface between stabilizer extension and stabilizer beam. The stabilizer extension is smaller than the stabilizer beam and it goes inside the beam. (Hiab, 2015)

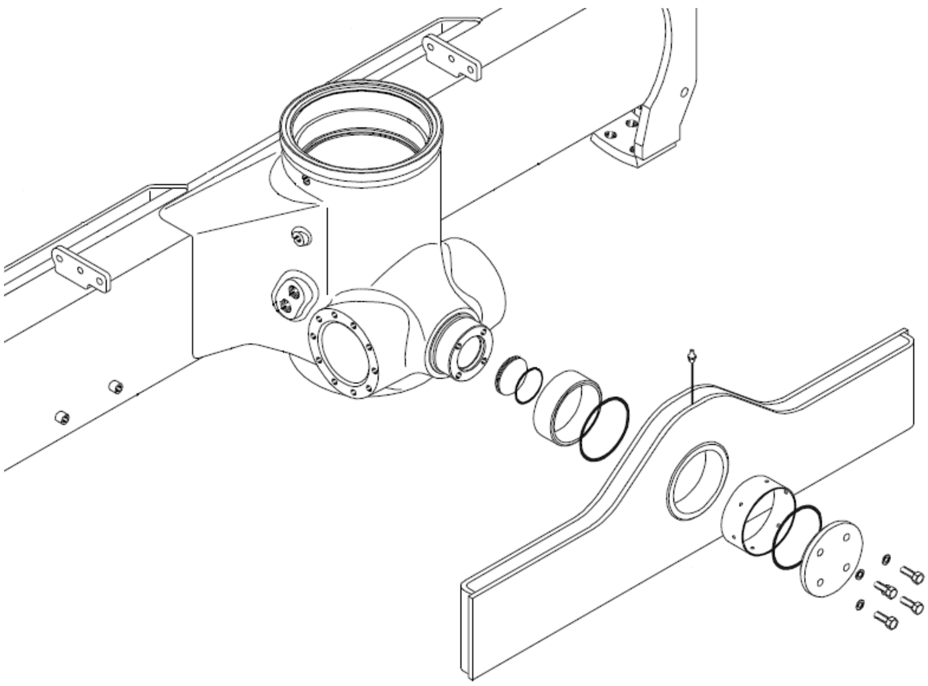

Figure 5.13. Interface between three-point bridge and base. The three-point bridge is connected with screws and a plate to the base housing. (Hiab, 2015)

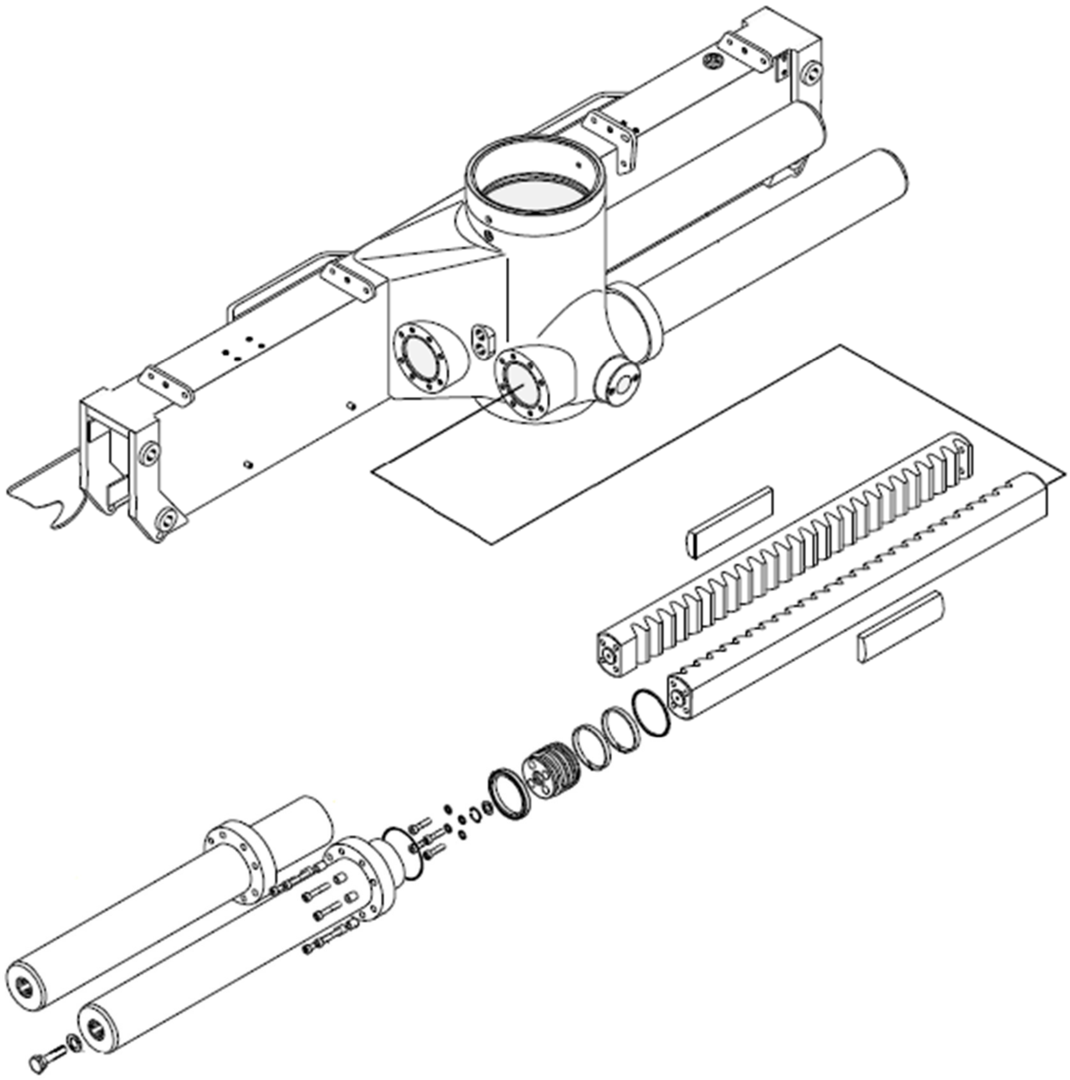

Figure 5.14. Interface between slewing cylinder and base. The slewing cylinders are connected with screws to the base housing. (Hiab, 2015)

The old solutions for connections between the parts were used to define a draft for the new interfaces.

5.5 Step 4: Target setting based on customer environment

Main points of this step:

- Analyzing which kind of products the customers need

In this step the customer environment and the old products are analyzed. First the order history of the old products and parts were analyzed to see how many different cranes and variants were sold in a certain period of time. The company didn’t have legible material on this kind of information and therefore the following figures were made for this study.

Figure 5.15 shows, in percentages, how many cranes have been sold in the time frame.

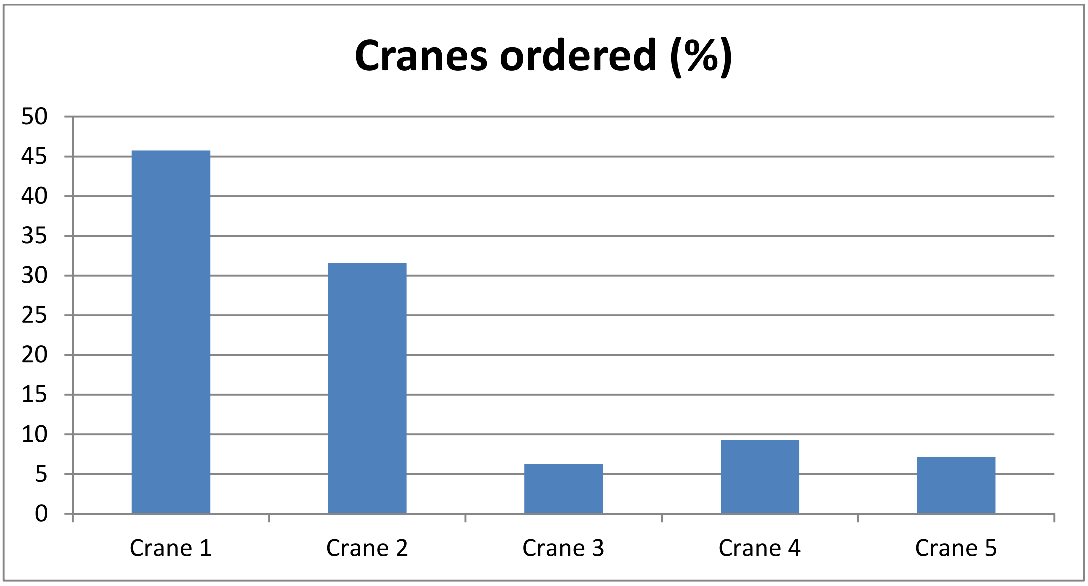

Figure 5.15. Percentages of sold cranes in the time frame.

From Figure 5.15 it can be seen that the smaller cranes are the most sold cranes in this study. Of all sold cranes circa 45% are crane 1 models. Crane 2 models are sold circa 30% and cranes 3, 4 and 5 models are each sold less than 10%.

Figure 5.16 demonstrates how many different parts for crane 1 have been sold. Because of confidentiality reasons the exact number of sold parts is not shown, but the ratio between the different parts can be seen. Figure 5.6 shows the structure of crane 1 and it shows that there are two different stabilizer legs for that crane. From Figure 5.16 it can be seen that stabilizer leg D with JIC connection is the most sold option for that crane.

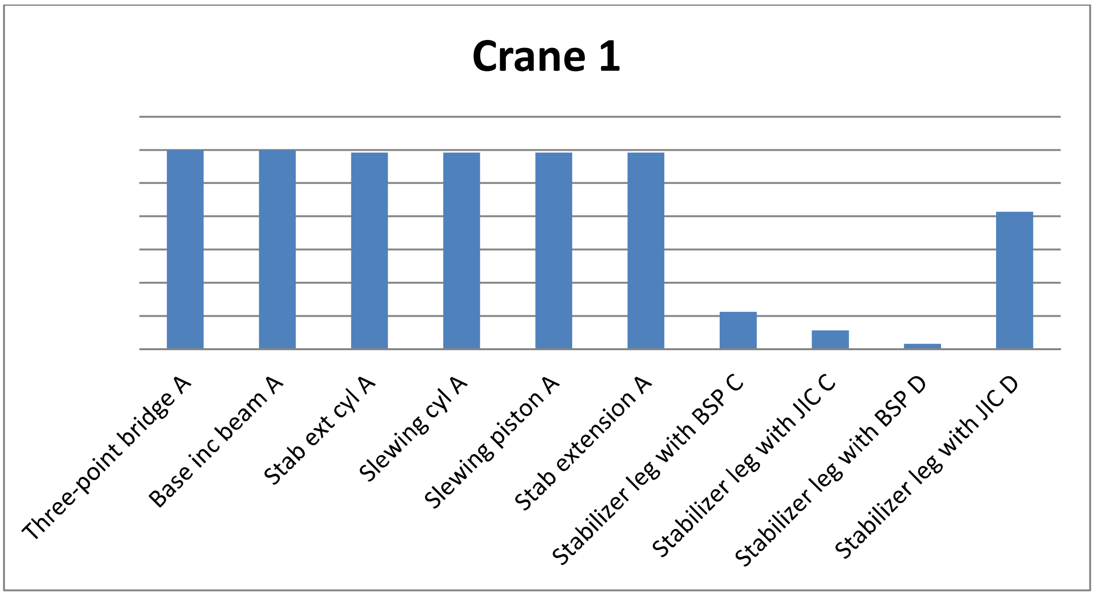

Figure 5.16. The number of different parts sold for crane 1.

As can be seen from Figure 5.7 crane 2 has more options from which the customer can choose from as crane 1. Crane 2 can be chosen with one of two different bases, four different stabilizer systems and three different stabilizer legs. Figure 5.17 shows how many different parts for crane 2 have been sold and it is clear that base B, stabilizer extension B and stabilizer leg D are the most ordered options.

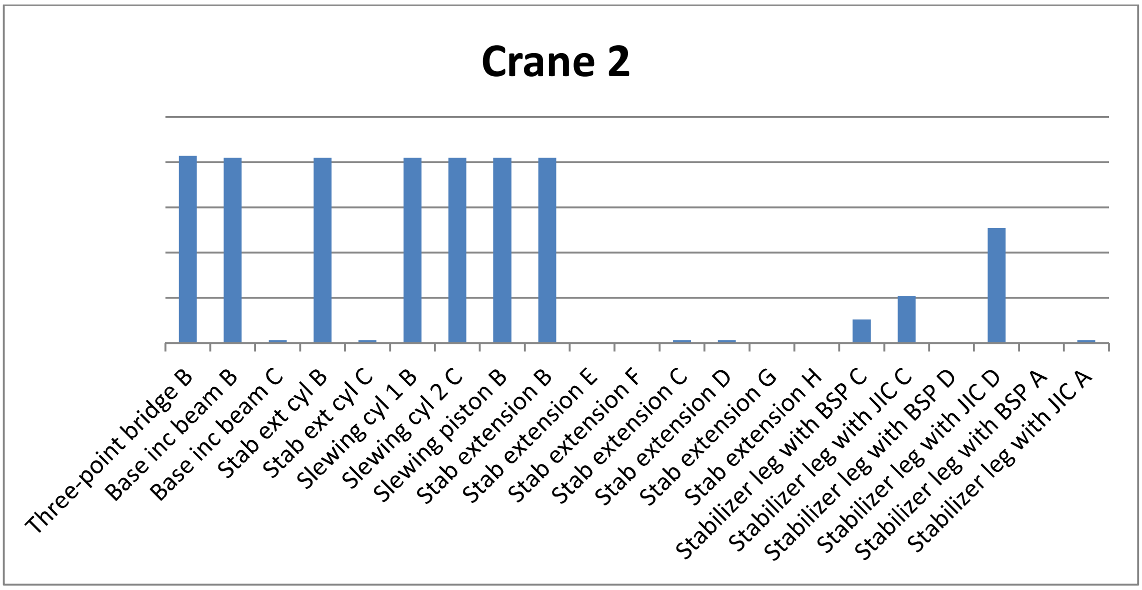

Figure 5.17. The number of different parts sold for crane 2.

Crane 3 has also some options to choose from as can be seen from Figure 5.8. The most ordered options for crane 3 are stabilizer beam A or B, stabilizer extension I and stabilizer leg B with BSP connection as shown in Figure 5.18.

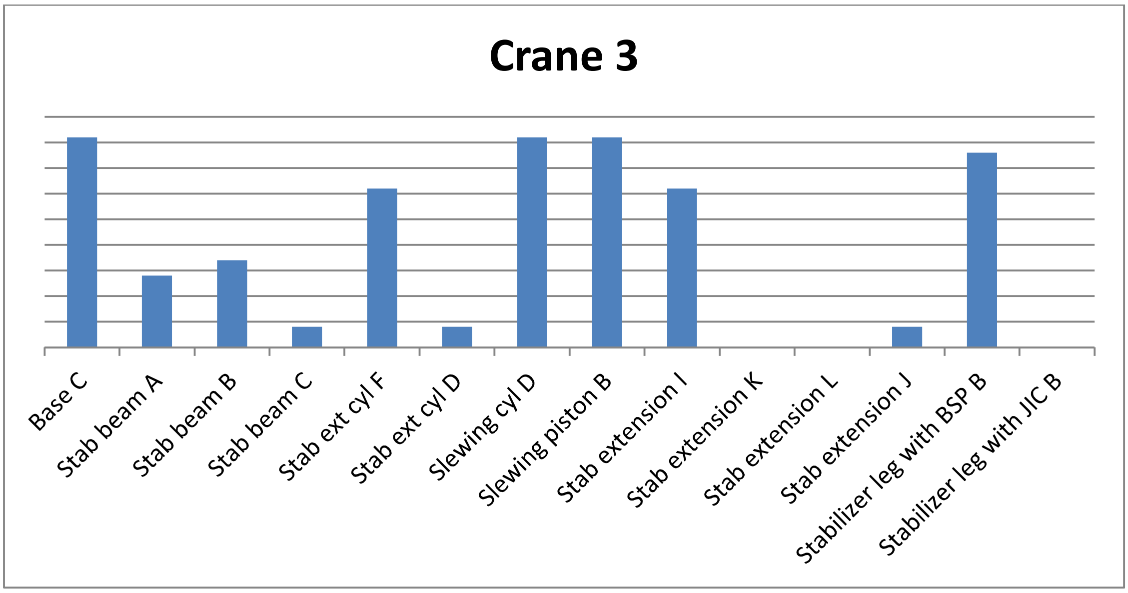

Figure 5.18. The number of different parts sold for crane 3.

Crane 4 and 5 have different bases, but otherwise they use the same parts and options. The main observation that can be made from Figure 5.19 and Figure 5.20 is, that many cranes have been ordered without a stabilizer system. The customer may use other stabilizer systems with the crane or he may use it stationary without a truck.

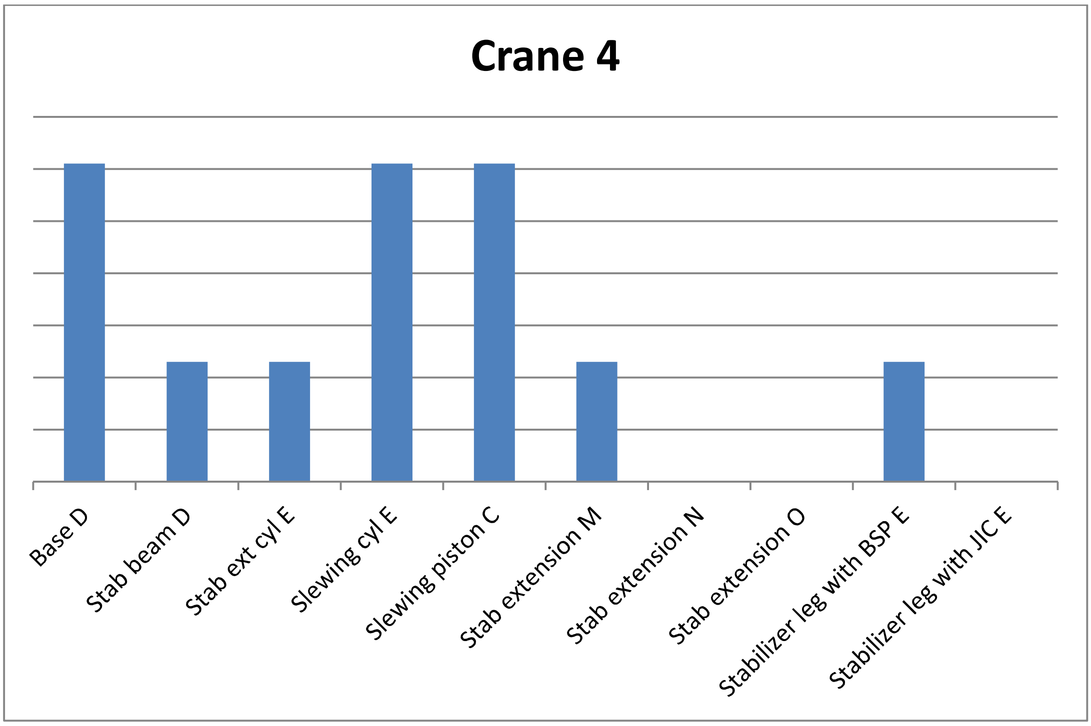

Figure 5.19. The number of different parts sold for crane 4.

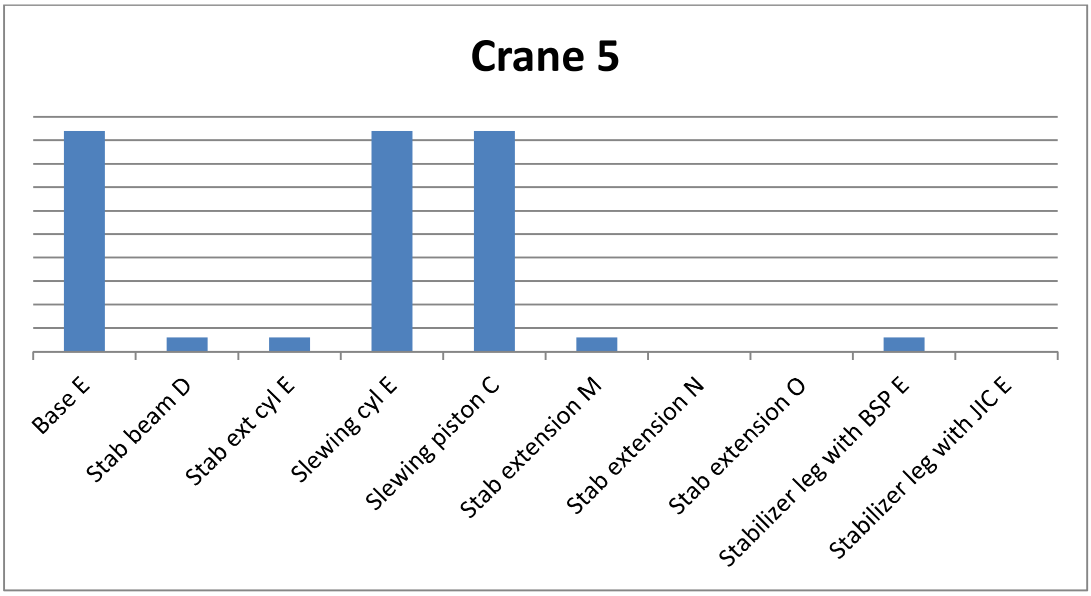

Figure 5.20. The number of different parts sold for crane 5.

The following figures will provide information about the number of ordered parts in comparison to one another. The cranes in the study use two different three-point bridges and the order ratio between those can be seen in Figure 5.21.

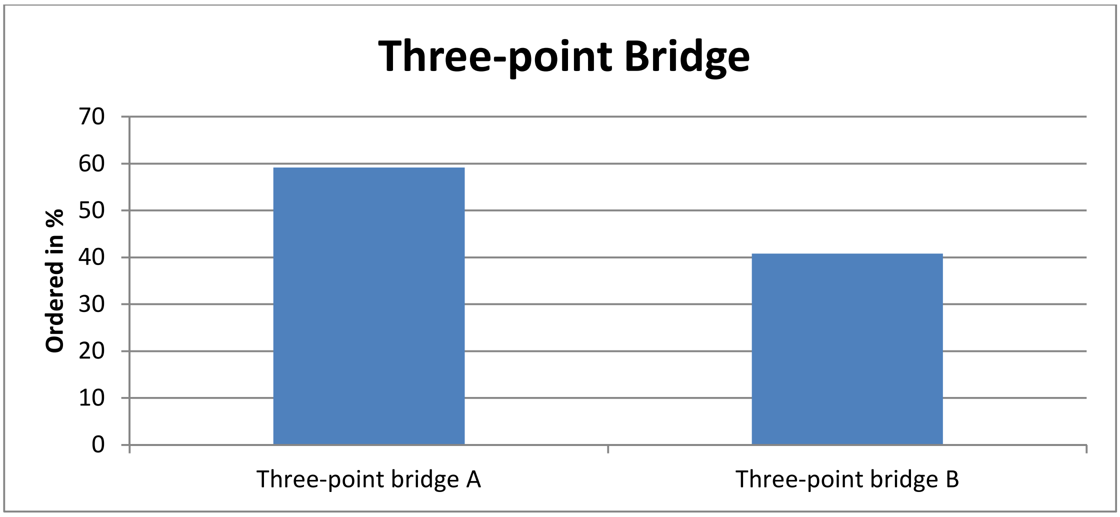

Figure 5.21. Number of ordered three-point bridges in percentages.

Every crane has a different base and therefore the number of ordered bases distributes in the same way than the number of ordered cranes. Crane 2 has two different bases, and as can be seen from Figure 5.22, base inc. beam C has been sold just a few times.

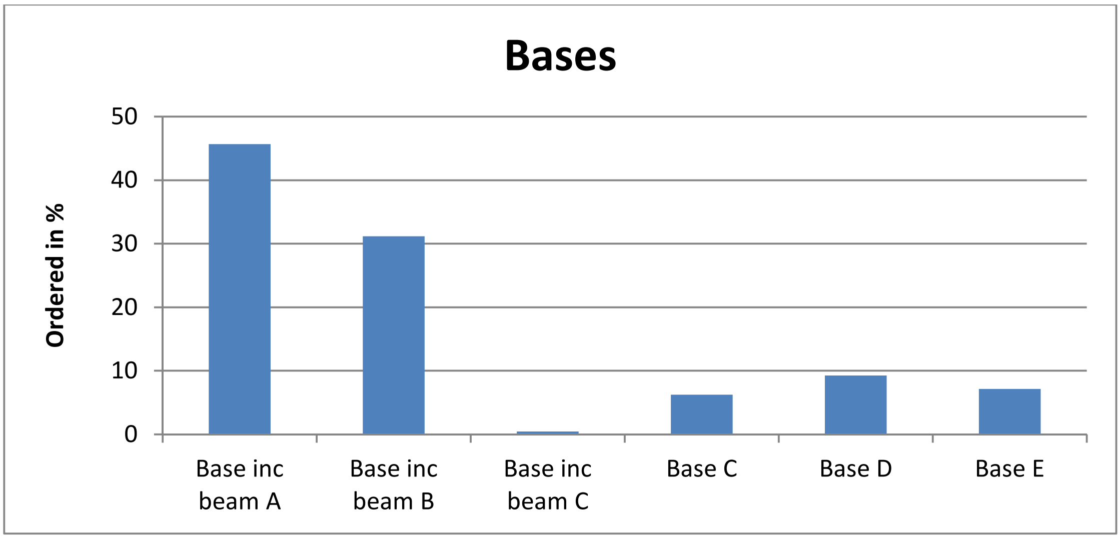

Figure 5.22. Number of ordered bases in percentages.

The two heavier cranes use both the same stabilizer beam D and thus they are sold the most. Stabilizer beams A, B and C are all options for crane 3. As can be seen from Figure 5.23 options A and B are ordered almost the same amount, but option C is ordered clearly less.

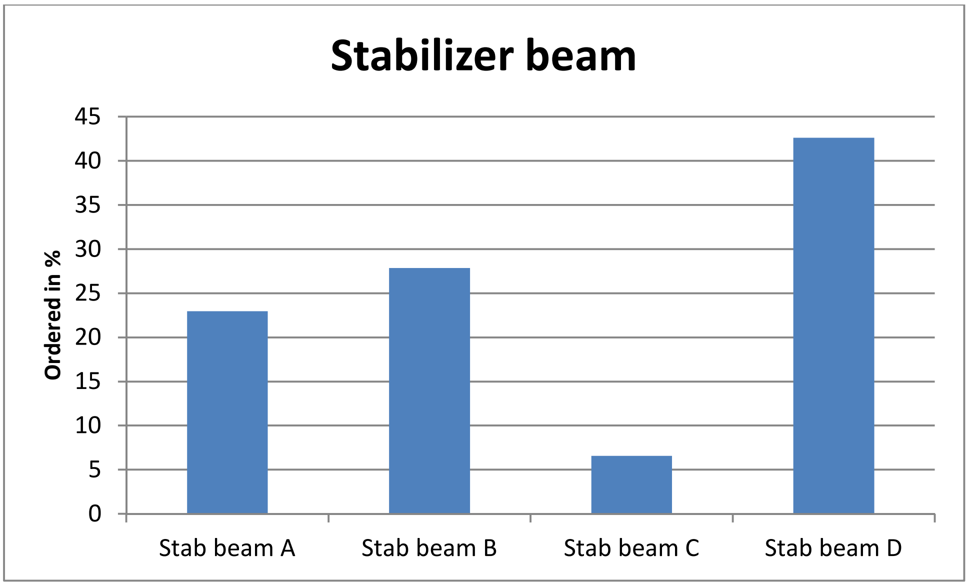

Figure 5.23. Number of ordered stabilizer beams in percentages.

Stabilizer extension cylinders C and D, which are options for crane 2 and 3, are only sold a few times. The other sold extension cylinders correspond somehow to the numbers of sold cranes, because each crane has its own stabilizer extension cylinder. The number of ordered stabilizer extension cylinders is shown in Figure 5.24.

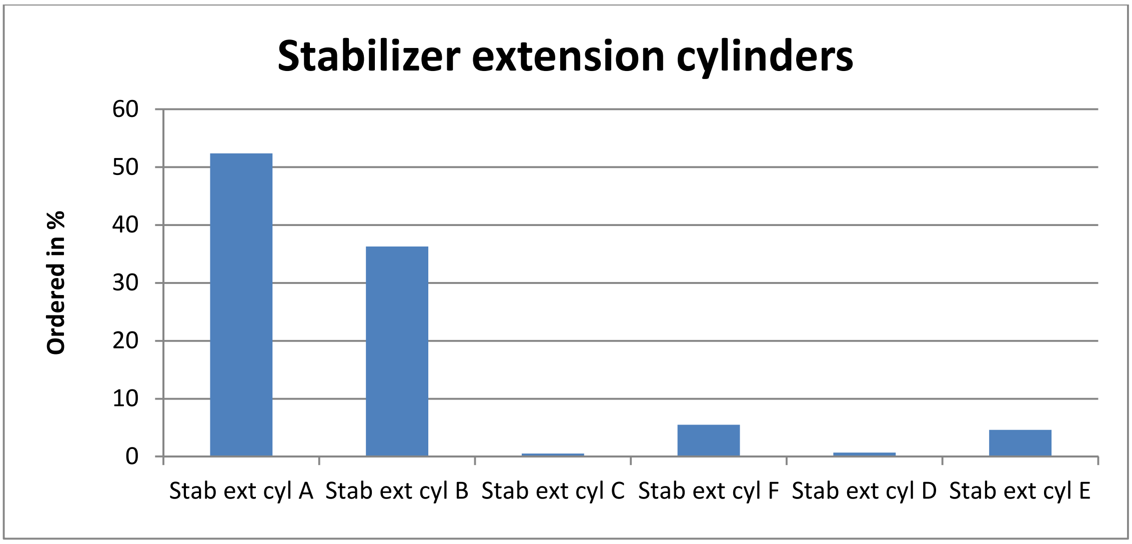

Figure 5.24. Number of ordered stabilizer extension cylinders in percentages.

Crane 4 and 5 use the same slewing cylinders and crane 2 uses always two different slewing cylinders. The other cranes use different slewing cylinders and consequently the number of ordered slewing cylinders corresponds to the number of ordered cranes as can be seen in Figure 5.25.

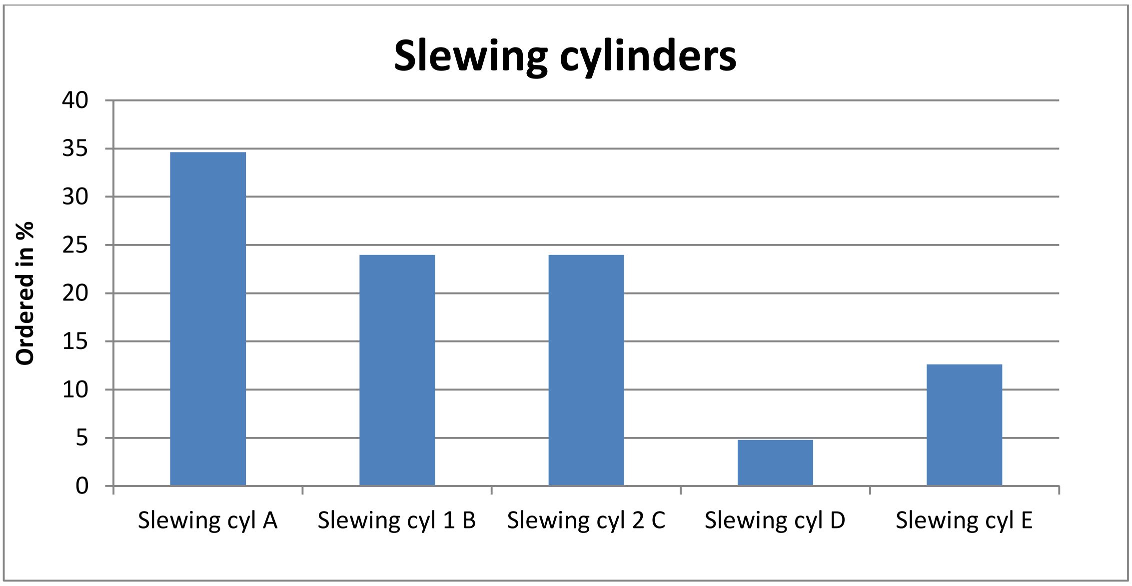

Figure 5.25. Number of ordered slewing cylinders in percentages.

Crane 1 uses slewing piston A, crane 2 and 3 use slewing piston B and crane 4 and 5 use slewing piston C. Therefore the number of ordered pistons corresponds to the number of ordered cranes that use them, as can be seen from Figure 5.26.

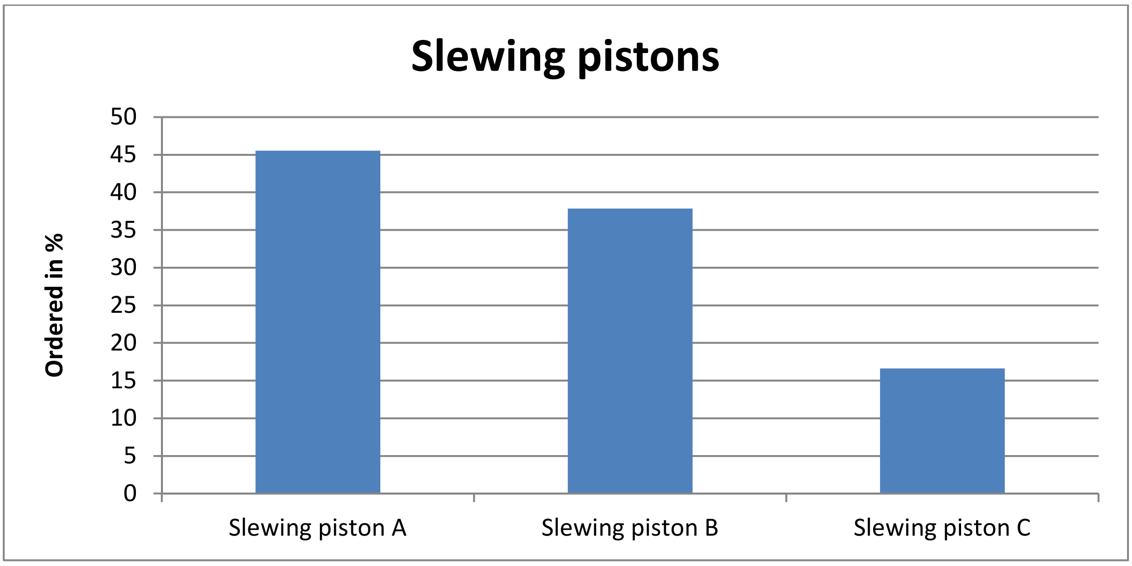

Figure 5.26. Number of ordered Slewing pistons in percentages.

Figure 5.27 shows the number of ordered stabilizer extensions. It can be seen that stabilizer extensions A and B are by far the most ordered ones, which is no surprise, because the most ordered cranes, 1 and 2, use them. Stabilizer extensions I and M are ordered with cranes 3, 4 and 5. Stabilizer extensions C, D and J, which are options for cranes 2 and 3, are ordered just a few times. Stabilizer extensions E, F, G, H, K, L, N and O are not ordered once in the time frame. They are all stabilizer extensions which are used with powerlift.

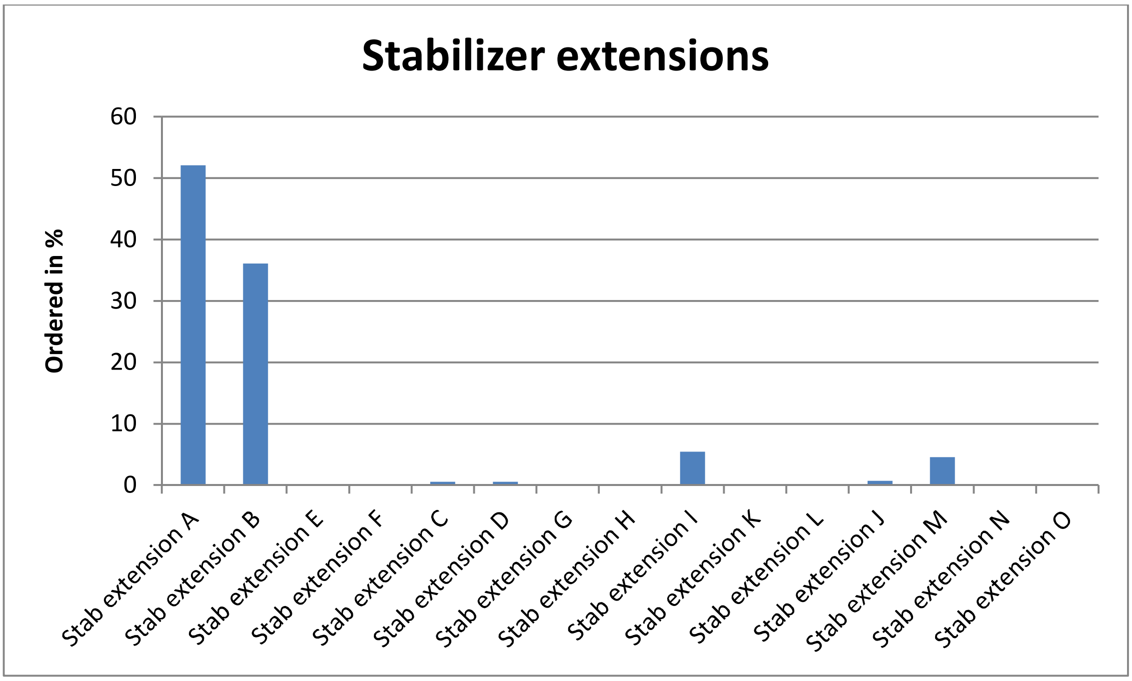

Figure 5.27. Number of ordered stabilizer extensions in percentages.

Almost 60% of all ordered stabilizer legs have been leg D with JIC connection as shown in Figure 5.28. Stabilizer leg C with BSP and with JIC connections have been the second most popular options. Stabilizer leg B (BSP/JIC) is the only option for crane 3 and stabilizer leg E (BSP/JIC) is the only option for cranes 4 and 5, so they have been also ordered sometimes. Stabilizer leg A with JIC is only ordered a few times as well as stabilizer leg D with BSP. Stabilizer leg A with JIC, B with JIC and E with JIC has not been ordered at all.

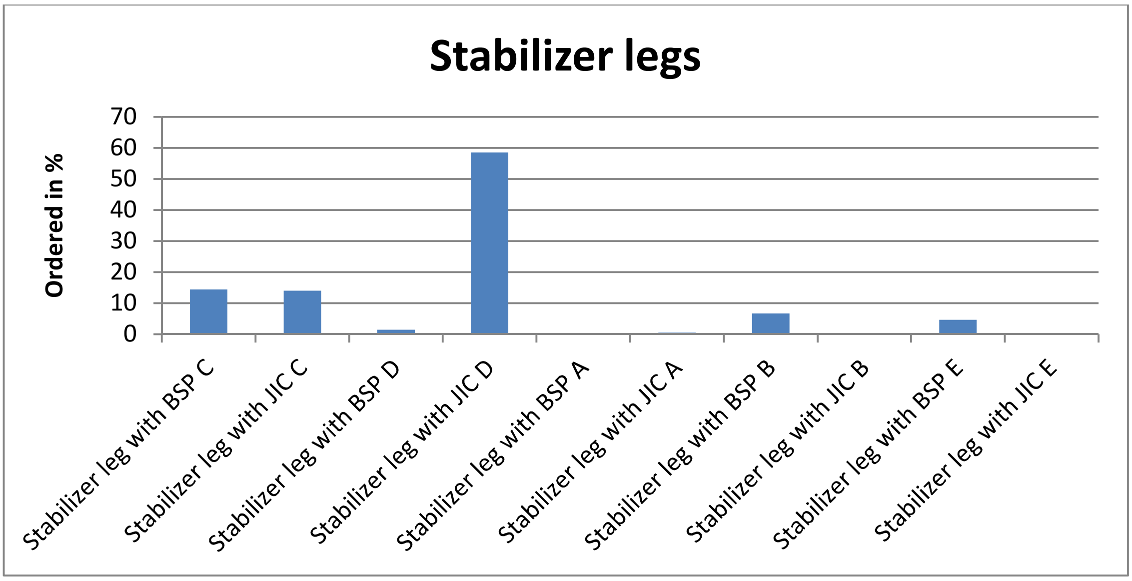

Figure 5.28. Number of ordered stabilizer legs in percentages.

The figures and information about the old cranes and parts gives an insight about the customer needs, but it tells only what the customers have ordered from the product family. It doesn't tell if there would be some other options that would fit the customer needs better than the existing options. This problem was considered more in step 5.

5.6 Step 5: Preliminary product family description

Main points of this step:

- Comparing customer requirements against the generic elements
- Analyzing the possibilities for standardization

In this step the relations between customer requirements and generic elements were analyzed. This was done by consulting with the marketing and sales teams of the company about the customer requirements, which cause the need for variation. Not every variation in the products could be explained by them, but a good general view about the situation was acquired.

The customer requirements were compared against the generic elements and thus the existing of every generic element was justified.

5.7 Step 7: Modular architecture: modules and interfaces

Main points of this step:

- Definition of the modular architecture of the product family

In this step the details and technical solutions for the modules and interfaces were decided. As demonstrated in step 4, there were a lot of parts and variants in the existing product family that were not ordered by the customers. The process began by eliminating the parts that were not in line with the customer requirements.

The different element types in this case were also discussed. Consideration was whether or not the elements were standard, configurable, partly-configurable or one of a kind. In this step the details of the interfaces between the elements were also decided. This step was fulfilled by analyzing the old products and solutions and with the help of earlier product deliveries and customer needs.

5.8 Step 9: Product family documentation

Main points of this step:

- Documenting of the modular product family

In this step PSBP drawings were made to document the product family. An example of a PSBP on an abstract level is given in Figure 5.29.

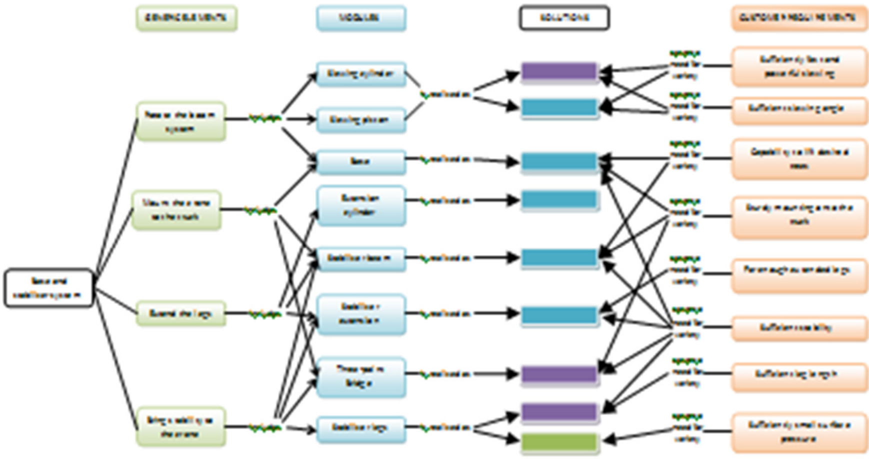

Figure 5.29. Example of a PSBP drawing from the case.

The example PSBP included from left to right the product family, generic elements, modules, solutions and customer requirements. The different solution types in this study were standard components, interchangeable modules without layout changes, interchangeable modules with layout changes and delivery specific elements.

5.9 Step 10: Business impact analysis

Main points of this step:

- Estimate the business impacts of the study

Although the case focused on a certain group of cranes and only on the base and stabilizer system of them, good results were obtained. The part number could be decreased even by 40%. In this case the part number refers to the parts that this study focused on. Every part in the study consists of other parts and subassemblies, therefore the reduction in the amount of part numbers is even greater. The best results were achieved by analyzing the delivered products and by studying the customer needs. Figure 5.30 shows the number of old parts compared to the number of new parts.

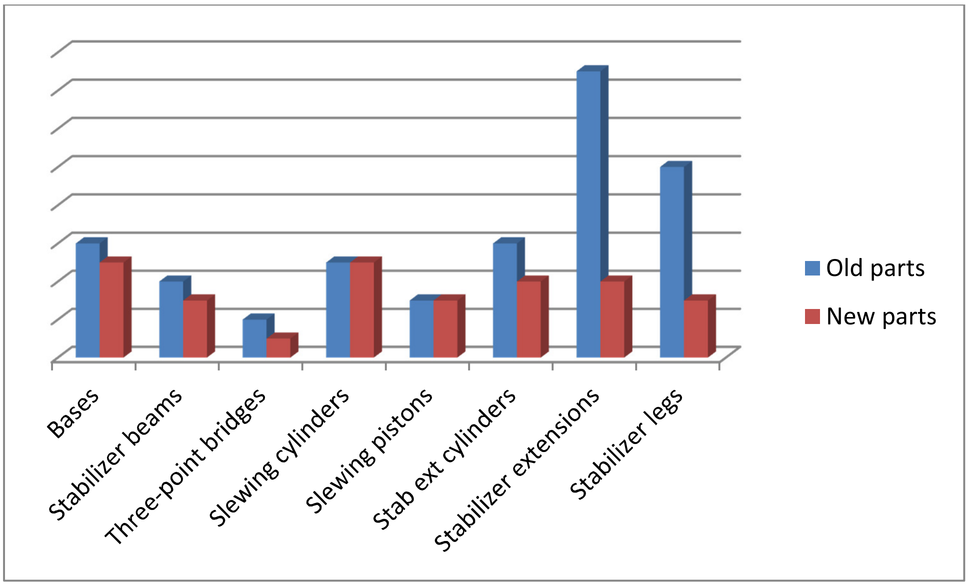

Figure 5.30. Number of old parts compared to new ones.

The main object for the case company was the decrease of part numbers. However by discussing about the results of the case example, other possible benefits for the company could be seen. After the case example was completed, Figure 4.11 was analyzed. It was noticed, that one benefit of the process was also that the customer requirements were updated. This meant that the products fit the customer requirements better, and thus would improve the sales. The results of the process also showed potential in enabling design re-use, which would have an effect on multiple areas. It would, for example, improve the R&D efficiency, because the designing of new components would be simpler. All in all the resulted modular product family would allow to free R&D resources or to focus them onto developing of new technologies, because the design principles, interfaces and module structure of the products have already been decided. The designing of new features or products would benefit a lot from this and it would enable changes during the use life cycle phase of the products.

The benefits for the company would not be limited to R&D. The reducing of part numbers and the modular structure of the products would also have an effect on the product costs. The manufacturing would be simpler, because fewer tools have to be used, and that has a direct impact on the costs. Also the controllability of production would be improved, since the managing of fewer parts is easier. New developing projects could be completed faster and therefore also the time to market would decrease. A possible benefit would also be risk reduction. With fewer parts, the testing and the trial runs would be easier and they could be made more precisely. Also the replacement of modules would allow for a reduced downtime and maintenance cost.

5.10 Summary of the study

This study proved that the case company would benefit from the use of the Brownfield Process to modularize their existing product family. The case products seem to fit well for this kind of process and some good results could be obtained. During this study, however, some issues came up, that have an effect on this kind of product developing projects.

First of all, the communication with the different teams and persons from the company turned out to be very important. It was sometimes hard to find the right person to answer a certain question about the products.

The main design principles, for the products this study focused on, were decided many years ago. Therefore the reason on why some things are designed in a certain way nowadays is, because it had been decided so in the past. The same parts and design principles are still used, even though the products could benefit from re-designing.

One thing to consider in a modularization project is also the naming of the new parts. It could be wise to name the parts and assemblies in a way, which tells directly if it is a standard part or module that could be used in certain assemblies.

Not only should the re-use of parts and components be pursued, but also the re-use of designing methods. The designers should know how and why some things have been designed in the past in such a way.

The modularization of the product family alone doesn’t have the desired long term benefits. The manufacturing and the purchase of components have to be re-thought, so that they benefit from the modular product structure. Also the sales process with the customer has to be changed. The sales team has to know how to sell a modular product. All in all modularity has to reach throughout the whole organization, and it must be part of the company strategy.

The company has to have a person or team that owns the interfaces and modules and they have to take responsibility for them. So that if an engineer makes some changes to the products, there is a certain person or group which ensures that the changes are allowed in the current modular product in terms of, for example, interfaces or space reservations.

6. CONCLUSIONS AND OUTLOOK

The aim of this thesis was to introduce the case company to modularity and show how to carry through a modular product development project. Design Structure Matrix, Function Structure Heuristic and Modular Function Deployment methods were introduced and compared. These methods didn't fit perfectly for the modularization of an existing product family, which was the intention of the company. The Brownfield Process was developed for this kind of modularization and therefore it was chosen for this study.

The theory chapter of this thesis focuses on describing of the Brownfield Process and it is intended to work as a step by step guide for the company. The process is described in as much detail as possible and by following the steps a modular product family can be achieved. This was demonstrated by a example case.

The aim of the example case was to show and teach the company how to apply the Brownfield Process to their existing products and demonstrate that they would benefit from a modularization project like this. Because of the limited resources and time the example case focused on just a certain range of products and only on some structures.

The scope of the example case was chosen by the help of initial studies. The author of this thesis studied the product structures in part of a different study before this project and in that study the chosen areas showed some improvement potential. The target setting of the process was done by discussing with the R&D Manager about the expected results, by the help of the cause-and-effect chain shown in Figure 4.2 and by analyzing the answers of a survey that was send to a multi-disciplinary group of people working at the company. The main problem that stands out was that during the years, the variability of products and the different customer requirements have increased the number of parts to be maintained considerably. The expectation was that with the help of a modular product family, this problem could be solved.

A draft of the module structure was defined by analyzing the existing product structures. The existing product family was analyzed and documented to show what the variations between the existing products are and what options for the products are available for the customer. At this point there emerged a few questions about the existing products, for example why there have to be two different locking mechanisms for the legs.

The analyzing of customer requirements was made by studying the quantities of delivered products and product variants. In addition the marketing and sales teams were interviewed to get a better insight on what the customers need. It was noticed that not every variation in the products could be explained by a specific customer need. Because of some designing and manufacturing reasons variations in the products were necessary. These variations could be reduced by re-designing, but if a great effort is needed to redesign them, the benefits could be minimal. From the information gained by studying the delivered products it could be noticed, that the product family included options that are sold rarely, if at all. This tells that the options do not fit the customer requirements, if the customers are not ordering these. So their maintenance is unnecessary or they have to be re-design to fit the customer needs better.

With the knowledge of the previous steps, the details of the technical solutions for the modules and interfaces were decided. It was done by analyzing the old products and solutions and by considering the customer requirements and earlier product deliveries. For example the use of JIC or BSP hose connections was discussed. It came up that the only customers that want the BSP connections are the Swedish. They have told that reason for this is that their local service providers don’t have spare parts for JIC connections. If the company would still provide in the future both connections, they had to maintain double the number of parts associated to the connections. If they would provide only JIC connections, some customers in Sweden would maybe change their crane brand. In situations like this the consequences have to be estimated. Is it worth it to maintain both connections to satisfy all customer needs?

The documenting of the product family was done by PSBP drawings. The relations between customer needs and generic elements could be seen from these drawings. Because of the simple structure of the focused area in this study the PSBP drawings didn’t offer as much information as they would in a more complex case. But the main idea of the PSBP drawings could be explained to the case company by the example drawings.

By realizing the proposed changes the part number could be decreased up to 40%. Figure 5.30 shows the number of old parts compared to the number of new parts. Because the parts in this study contain other parts and subassemblies the effects are even greater. In addition to the decreased part number other benefits for the case company could be seen. These benefits included, among other things, updated customer needs, improved R&D efficiency, decreased time to market and risk reduction. Because this study was only an example case which was not really concretized it is hard to estimate the real and precise results of the case. However the results that could be obtained showed that it is clear that the case company would benefit from a modular product family.

The proposals, which resulted from the case study, were not concretized at the company during this thesis work. This thesis was intended rather to show the company how to fulfill a modularization process and what kind of benefits could be expected. The case study still brought to light some areas of the current product family which may need some re-designing or consideration in the future.

During this thesis it was not possible to make a proposal for modularization of the whole product family. It would be interesting to see, what kind of results could be accomplished if this process would be implemented to the whole product family of the case company. This would need a team to fulfill the study and full cooperation and commitment from the different experts of the company.

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